Senior Thesis

An Examination of the Characteristics of Seasonal Recharge in Ohio Based on Well Hydrographs

by

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Approved by

E Scott Bair

Dr. E. Scott Bair

ABSTRACT

This thesis endeavors to better define the characteristics of seasonal recharge changes to the confined and unconfined aquifers in Ohio. Aquifers in Ohio display characteristic fluctuations in water levels produced by seasonal variations in rates of ground water recharge. Recharge rates vary annually due to a combination of several factors including precipitation, evapotranspiration, and temperture among others. Characteristics of seasonal variations in recharge examined in this study include: the duration of the recharge period, the apparent amount of annual recharge, the duration of the discharge period, and the weeks of recharge commencement and cessation. This study is intended to quantitatively examine the seasonal characteristics of recharge in Ohio's aquifers.

Eight years of data were collected from eight observation wells completed in unconfined aquifers and nine observation wells completed in confined aquifers. The wells for this study were chosen from the observation well network maintained by the Ohio Department of Natural Resources and are intended to represent aquifers with yearly fluctuations that reflect natural conditions of the aquifer remote from the effects of pumping centers.

To better interpret the geologic framework of the aquifers in which these wells are constructed, well logs from surrounding domestic wells were used to construct hydrogeologic cross sections.The well-log data were compiled from files at the Ohio Department of Natural Resources, Division of Ground Water Survey.

Measurements from hydrographs from confined and unconfined aquifers were then compiled and examined to statistically evaluate the cyclic nature of recharge characteristics. Histograms and probability plots were constucted for each characteristic to quantify the interpretation of the characteristics studied.

The recharge characteristics of the aquifers examined in this study agree well with their expected behavior and ranges. Recharge to aquifers in Ohio typically begins during the month of October, generally lasting 6 months, and ends during the month of May. The apparent amount of recharge ranged from a mean of 4.5 feet for confined aquifers to 7 feet of water-level rise for unconfined aquifers. The average duration of the discharge period for both types of aquifers was 6 months.

Acknowledgements

I would like to extend my appreciation to Dr. E. Scott Bair for his suggestion of this project, and his assistance and guidance. I would also like to thank Jim Raab and the Ohio Department of Natural Resources, Division of Ground Water Survey whose well-log files were generously made available to me. Finally, I gratefully acknowledge the help of Jeff de Roche and the U.S. Geological Survey for permission, instruction, and assistance in using their ADAPS computer network and database to generate hydrographs from the observation wells examined in this study.

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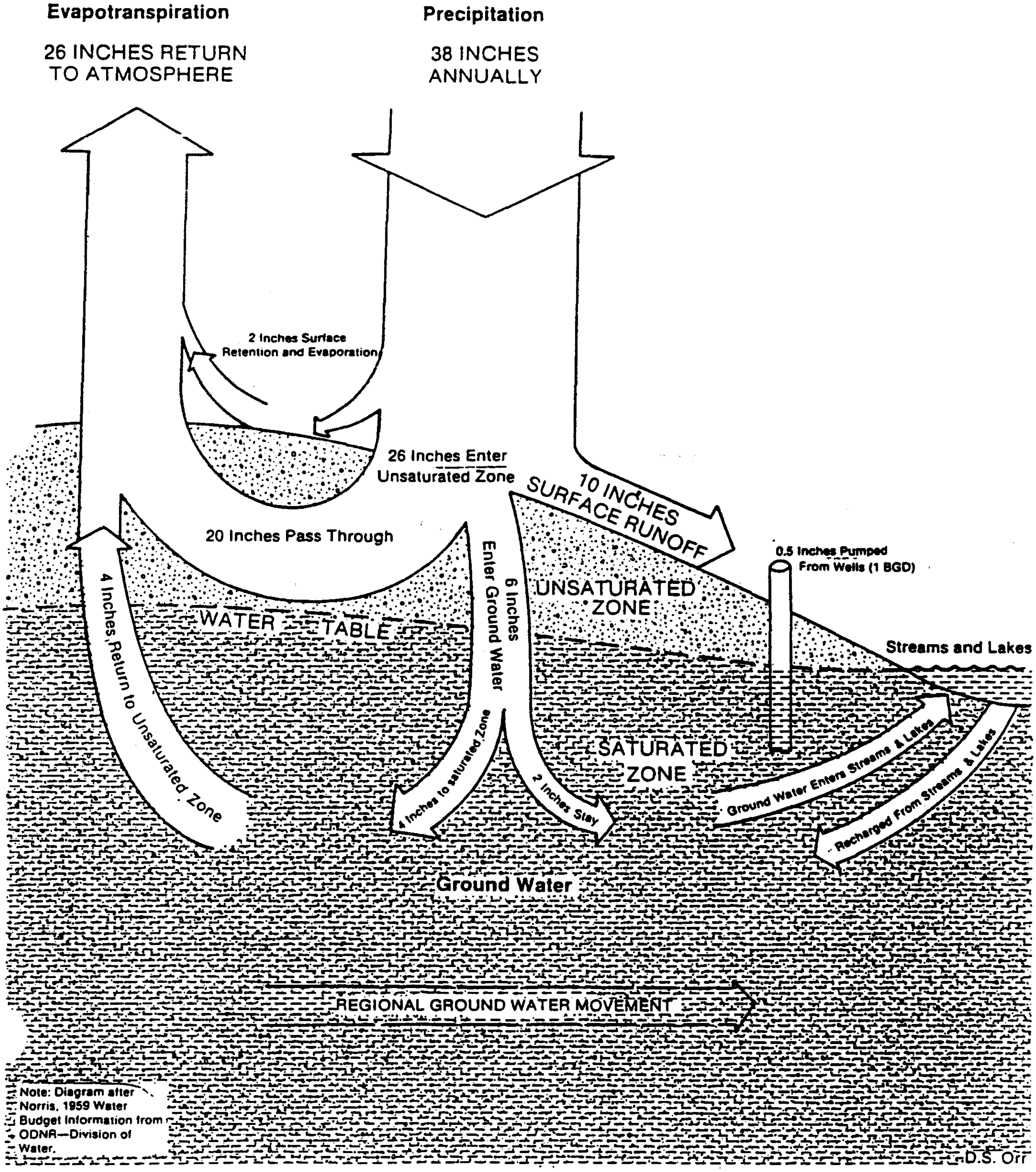
INTRODUCTION

The reliance on groundwater in Ohio increases every year as our growing population and industrial usage puts greater demands on our water resources. Consequently, the more we can improve our understanding of the dynamics of recharge and discharge to these aquifers the better it will permit us to manage this finite and valuable resource. Each year, aquifers throughout Ohio exhibit seasonal fluctuations in waterlevels. Ground-water levels are controlled by a combination of many factors, each of which can vary to a great extent. Figure 1 depicts the hydrologic budget of Ohio which shows how precipitation is distributed within the hydrologic cycle, including the components dealing with ground-water flow.

Seasonal fluctuations in ground-water levels can be classified into two major periods: the period of recharge to the aquifer and the period of discharge from the aquifer. Ground-water recharge depends on many factors, including precipitation, seasonal temperture variations, topographic relief, hydraulic conductivity, and depth to the water table among others. In an average water year, which runs from October 1st through September 30th of the following year, ground-water levels go from a point of maximum depth below land surface to a minimum depth below land surface, and then begin another decline. Figure 2 is an example of a well hydrograph and shows the characteristic seasonal fluctuations of water levels in an aquifer. These yearly fluctuations are caused by a combination of the generally greater amount of precipitation during winter months and higher amounts of evaporation and transpiration in the summer months. Commonly the recharge period lasts from October through May and is a result of the higher winter precipitation levels, the reduction in evaporation due to cooler tempertures, and the reduction in transpiration

Figure 1. Ohio's hydrologic budget (from Norris - ODNR)



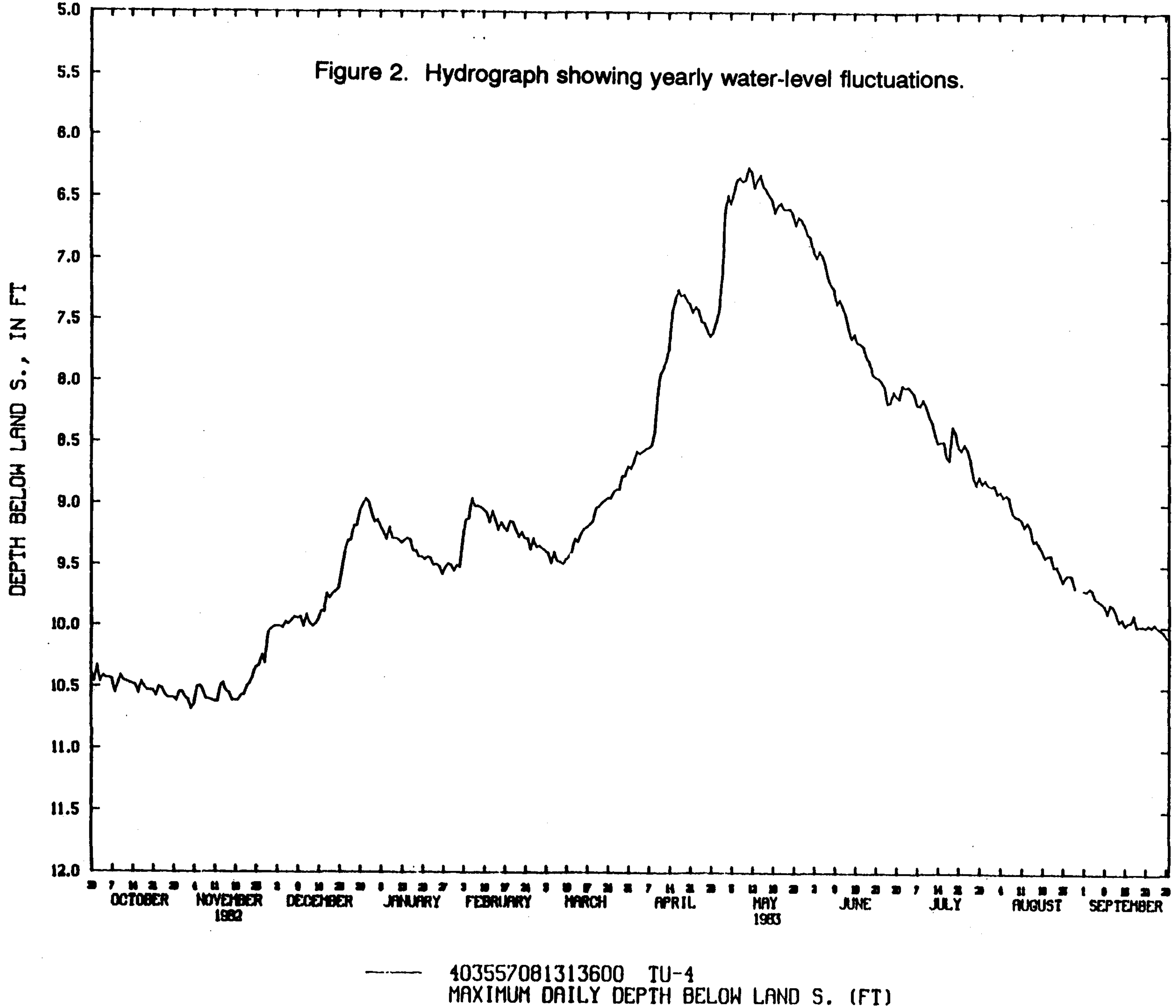


Figure 2. Hydrograph showing yearly water-level fluctuations.
DEPTH BELOW LAND S., IN FT
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
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11.0
11.5
12.0
OCTOBER
NOVEMBER
1982
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
1983
JUNE
JULY
AUGUST
SEPTEMBER
403557081313600 TU-4
MAXIMUM DAILY DEPTH BELOW LAND S. (FT)

due to the annual winter quiescentcy of the majority of plants.The period of discharge generally lasts from May through September and is a consequence of less precipitation combined with greater tempertures and evapotranspiration rates. Other factors that can influence ground-water levels include large-scale pumping of the aquifer and various surface-water boundaries such as lakes, rivers, and streams.

Statement of the Problem

Water levels measured in wells in confined and unconfined aquifers in Ohio display seasonal fluctuations. Not only do these fluctuations vary in time and magnitude, but also vary year-by-year in the same well. Water-level data in the form of well hydrographs give us a valuable tool with which to observe behavior and trends occurring in aquifers of interest. The correct interpretation of well hydrographs can provide a better definition of annual periods of recharge and discharge to aquifers. In addittion, if enough years of information are available, the effects of droughts and exceptionally wet years on aquifer water levels can be determined.

Seasonal fluctuations in ground-water levels can be misinterpreted if these seasonal variations are not quantified and evaluated. Because recharge to unconfined aquifers and confined aquifers is due to different mechanisms, any statistical analysis of recharge characteristics should address each type of aquifer separately. The goal of this study is to use the most representative data from Ohio's aquifers to statistically evaluate recharge characteristics of confined and unconfined aquifers.

Purpose and Scope

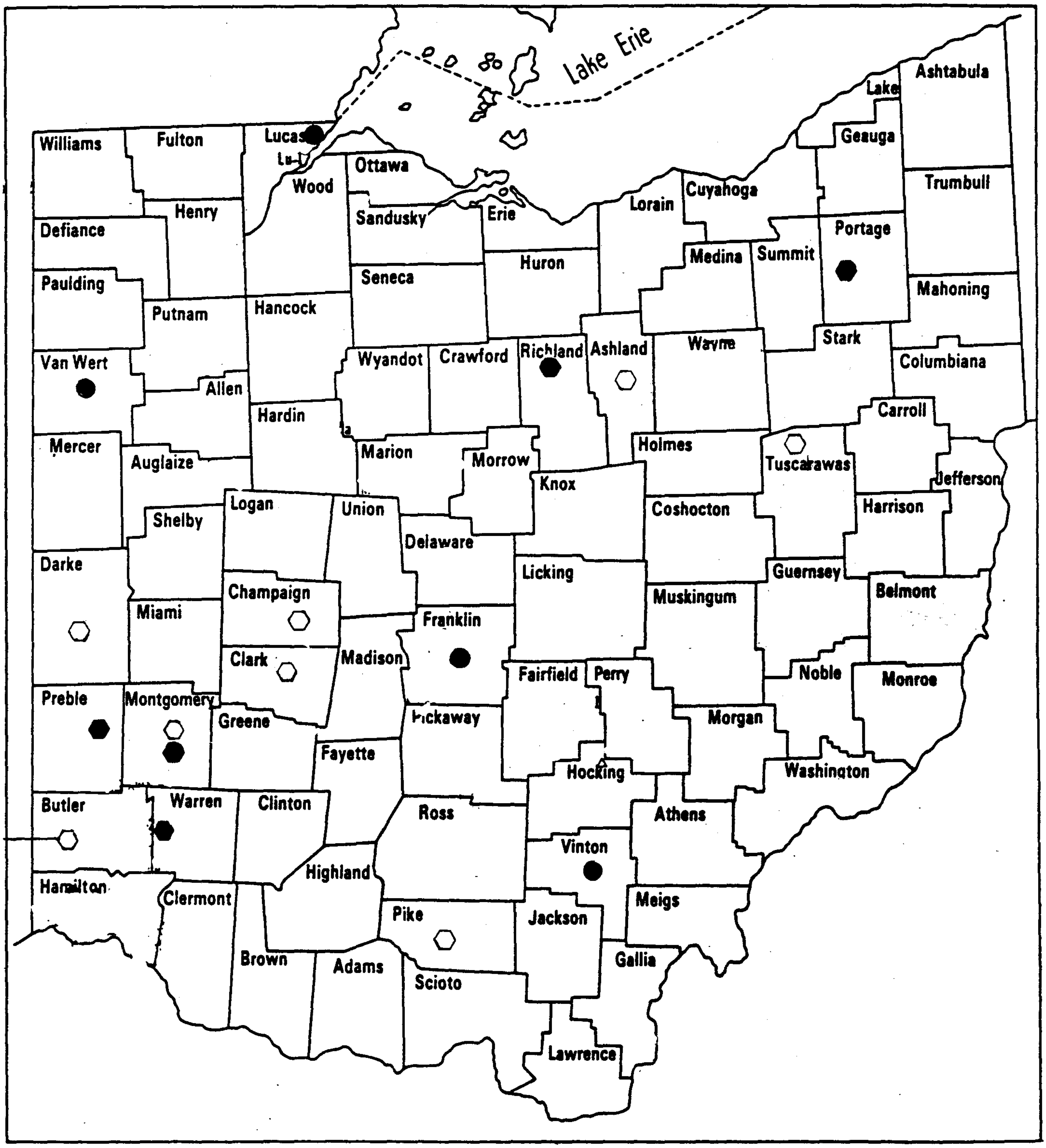
This thesis presents a statistical evaluation of the seasonal characteristics of recharge to unconfined and confined aquifers in Ohio. Water-level data were collected from wells throughout Ohio and were chosen to be representative of aquifers with water levels relatively unaffected by outside influences such as pumping.

The specific goals of this study are to measure and statistically evaluate seasonal water-level fluctuations recorded on well hydrographs. These characteristics include; (1) the duration of the annual recharge period (weeks), (2) the apparent amount of annual recharge (feet), (3) the duration of the annual discharge period (weeks), and (4) the weeks of commencement and cessation of the annual recharge period.

This report includes the results of eight years of water-level measurements in the form of water year hydrographs for nine confined aquifers and eight unconfined aquifers in Ohio. Figure 3 shows the locations of the observation wells examined in this study. The geographic distribution of the principal aquifers in Ohio is displayed in Figure 4.

The methods used in this study may be utilized for comparisons between aquifers of similiar makeup and for long-term trends in an individual aquifer. Long-term data combined with local precipitation data can help to identify aquifers that are undergoing drought conditions or suffering from overutilization.

Figure 3. Location of observation wells used in this study.



LEGEND

UNCONSOLIDATED UNCONFINED

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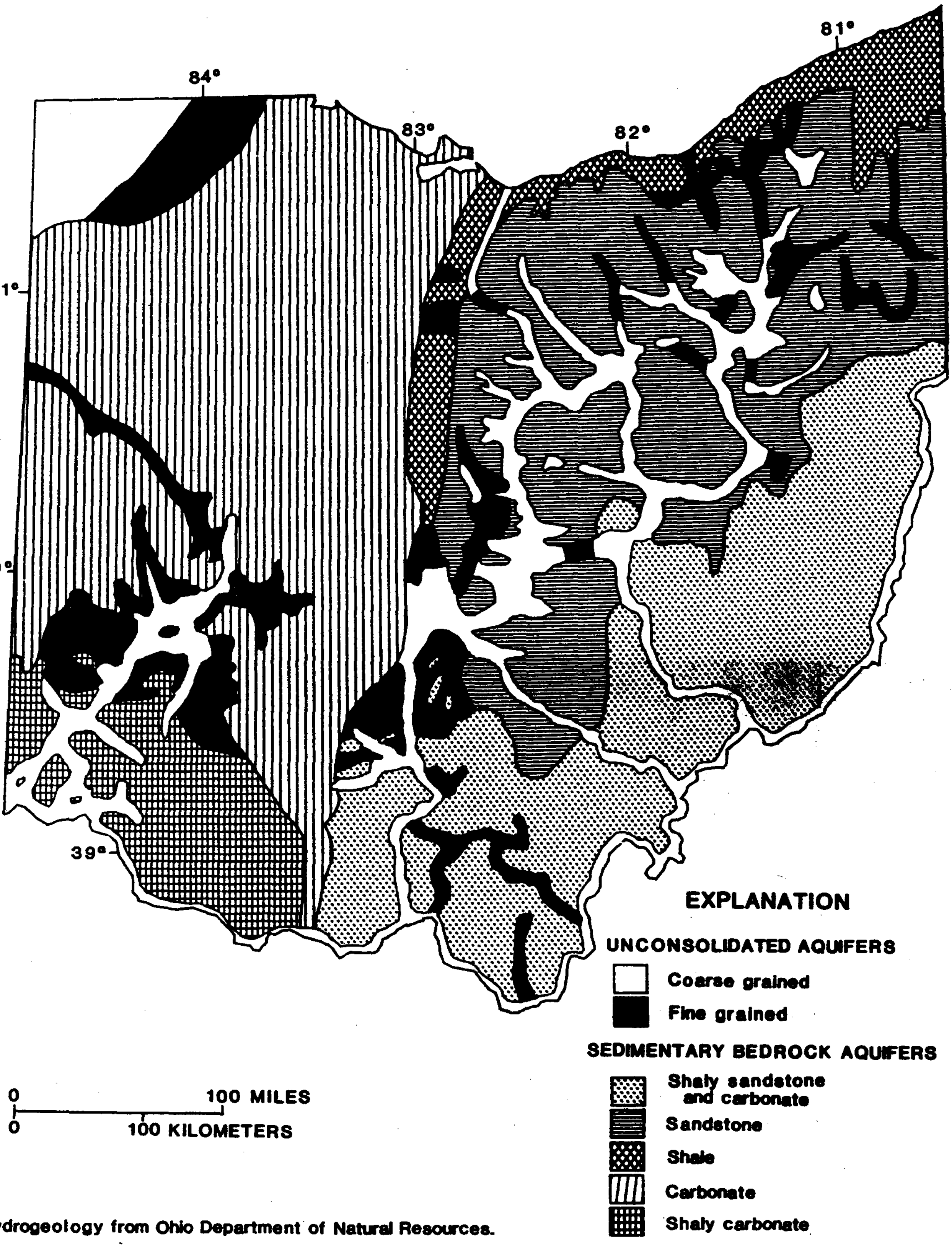
BEDROCK UNCONFINED

BEDROCK CONFINED

Figure 4. Geographic distribution of principal aquifers in Ohio (from ODNR).



Hydrogeology from Ohio Department of Natural Resources.

Previous Studies

Water-level fluctuations in Ohio's aquifers have deen examined previously. A report by Kaser and Klein (1963) investigated 14 years of water-level data from 20 observation wells. Kaser and Klein (1963) utilized a statistical approach to examine the frequency of occurrence of low ground-water levels. They developed frequency distributions of low ground-water levels and duration curves developed from these distributions. Their study was one of the first to use statistics to evaluate ground-water levels and was undertaken to more adequately describe ground-water situations, make the data more readily available, and to effect greater attention on the subject of ground-water levels.

Another investigation into ground-water recharge characteristics was that of Pettijohn and Henning (1979). The primary purpose of their investigation was to develop generalized maps of effective ground-water recharge rates for each of the 12 major drainage basins in Ohio. These maps of recharge rates were based mainly on data derived from stream hydrograph separations and flow-duration curves. For this purpose, Pettijohn and Henning (1979) created a computer program which calculated recharge based on stream flow separation

Methods of Analysis

Data utilized for this study were compiled from annual hydrographs from 17 wells selected from the Ohio observation well network maintained by the Ohio Department of Natural Resources. Observation wells initially were chosen based on an examination of their hydrographs in the 1991 edition of Water Resources Data of Ohio published by the U.S. Geological Survey. For each well, hydrographs were obtained for eight water years dating from 1982-1983 through 1989-1990. Tables 1and 2 list the observation wells completed in unconfined and confined aquifers, respectively, used in this study along with their location, well construction, and aquifer characteristics. Wells were intentionly chosen so that water-level fluctuations were the result of natural seasonal variations and not due to or dominated by artificial disturbances such as pumping.

Five hydrograph characteristics were measured. Results of these measurements were then analyzed by the statistical program GEOEAS which generated probability histograms and probability plots for each hydrograph characteristic. The results of the statistical evaluations are intended to represent the general seasonal nature of recharge to Ohio's confined and unconfined aquifers.

TABLE 1

LISTING OF OBSERVATION WELLS USED IN THIS STUDY
UNCONFINED AQUIFERS

ODNR WELL NUMBER	COUNTY	WELL DEPTH AND CONSTRUCTION STYLE	AQUIFER DESCRIPTION
AS-2	Ashland	6 in diameter, depth 64 ft, cased	Sand and gravel of Pleistocene age
BU-56	Butler	5 in diameter, depth 58 ft, cased	Sand and gravel of Pleistocene age
CH-3	Champaign	8 in diameter, depth 40 ft, cased	Sand and gravel of Pleistocene age
CL-7	Clark	6 in diameter, depth 50 ft cased	Sand and gravel of Pleistocene age
D-2	Darke	6 in diameter, depth 70 ft cased	Sand and gravel of Pleistocene age
MT-3	Montgomery	8 in diameter, depth 60 ft cased	Sand and gravel of Pleistocene age
PI-2	Pike	6 in diameter, depth 60 ft cased	Sand and gravel of Quaternary age
TU-4	Tuscarawus	6 in diameter, depth 42.5 ft cased	Sand and gravel of Pleistocene age

TABLE 2

LISTING OF OBSERVATION WELLS USED IN THIS STUDY
CONFINED AQUIFERS

ODNR WELL NUMBER	COUNTY	WELL DEPTH AND CONSTRUCTION STYLE	AQUIFER DESCRIPTION	CONFINING LAYER
FR-10	Franklin	4 in diameter, depth 75 ft, cased	Sand and gravel of Pleistocene age	70 ft thick clay layer
LU-1	Lucas	12 in diameter, depth 523 ft, cased	Limestone of Silurian age	40 ft thick clay layer
MT-6	Montgomery	8 in diameter, depth 60 ft, cased	Sand and gravel of Pleistocene age	20 ft thick clay layer
PO-6	Portage	8 in diameter, depth 72 ft cased	Sand and gravel of Pleistocene age	50 ft thick clay layer
PR-2	Preble	6 in diameter, depth 78.5 ft cased	Sand and gravel of Pleistocene age	>50 ft thick clay layer
R-3	Richland	8 in diameter, depth 150 ft cased	Sand and gravel of Pleistocene age	>50 ft thick clay layer
V-1	Vinton	6 in diameter, depth 218 ft cased	Sandstone of Mississippian age	>100 ft thick shale and clay
VW-1	Vanwert	8 in diameter, depth 340 ft cased	Limestone of Silurian age	50 ft thick clay layer
W-5	Warren	12 in diameter, depth 121 ft cased	Sand and gravel of Pleistocene age	110 ft thick clay and shale

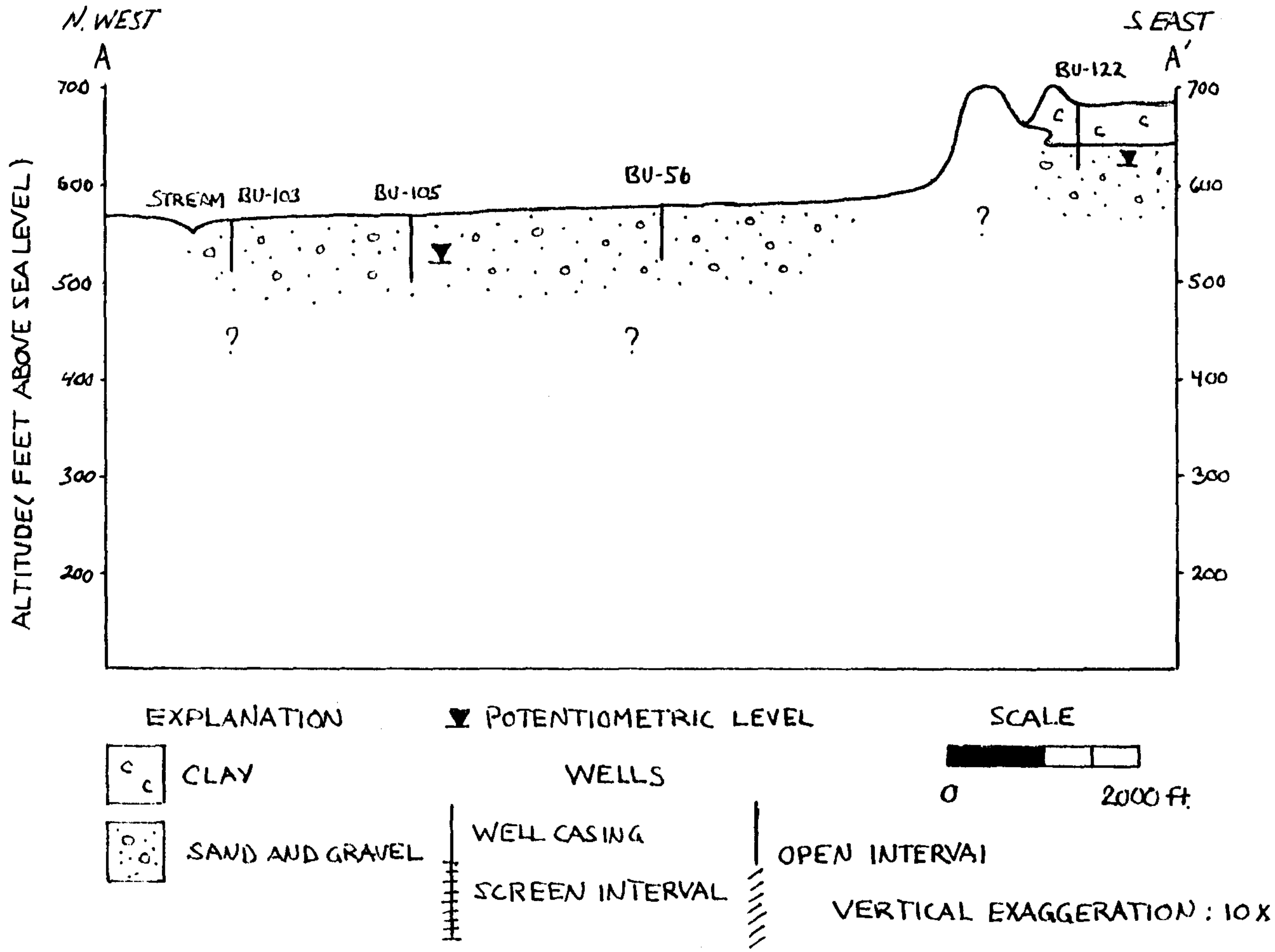
GEOLOGIC SETTING

Ohio lies between two major physiographic provinces, the Central Lowlands and the Appalachian Plateau. The low elevation northwestern part of the state comprises the Central Lowlands whereas the high relief southwestern portion of the state makes up the Appalachian Plateau. Ground-water supplies from the northwestern portion of the state are obtained from extensive outwash deposits and thick sequences of fractured limestone. In the Appalachian Plateau, ground water is derived mainly from localized aquifers composed of outwash, fractures in shale, or alluvium.

The statistical characteristics of recharge are compiled for two main types of aquifers, confined and unconfined, and for a variety of rock types including unconsolidated material along with limestones and sandstones. Recharge to unconfined aquifers is controlled by precipitation, infiltration, evapotranspiration, and runoff, whereas recharge to confined aquifers is controlled by leakage across confining beds and recharge in outcrop areas. As a result, their hydrograph responses should not necessarily be similiar and could be quite different.

Of the eight observation wells studied for unconfined aquifers, all were completed into Pleistocene sand and gravel deposits. These unconsolidated materials generally consist of interbedded sand, gravel, cobbles, with some clay, and generally represent deposits formed by the last period of glaciation. These deposits are generally highly permeable and constitute very important sources of ground water in Ohio. Recharge to these aquifers occurs as a combination of precipitation and subsequent infiltration, as well as inflow from losing streams and rivers.The majority of the wells completed into unconfined aquifers are constructed to depths less than 70 feet. Figure 5 is a hydrogeologic cross section through an unconfined aquifer and

Figure 5. Hydrogeologic cross section of an unconfined aquifer.

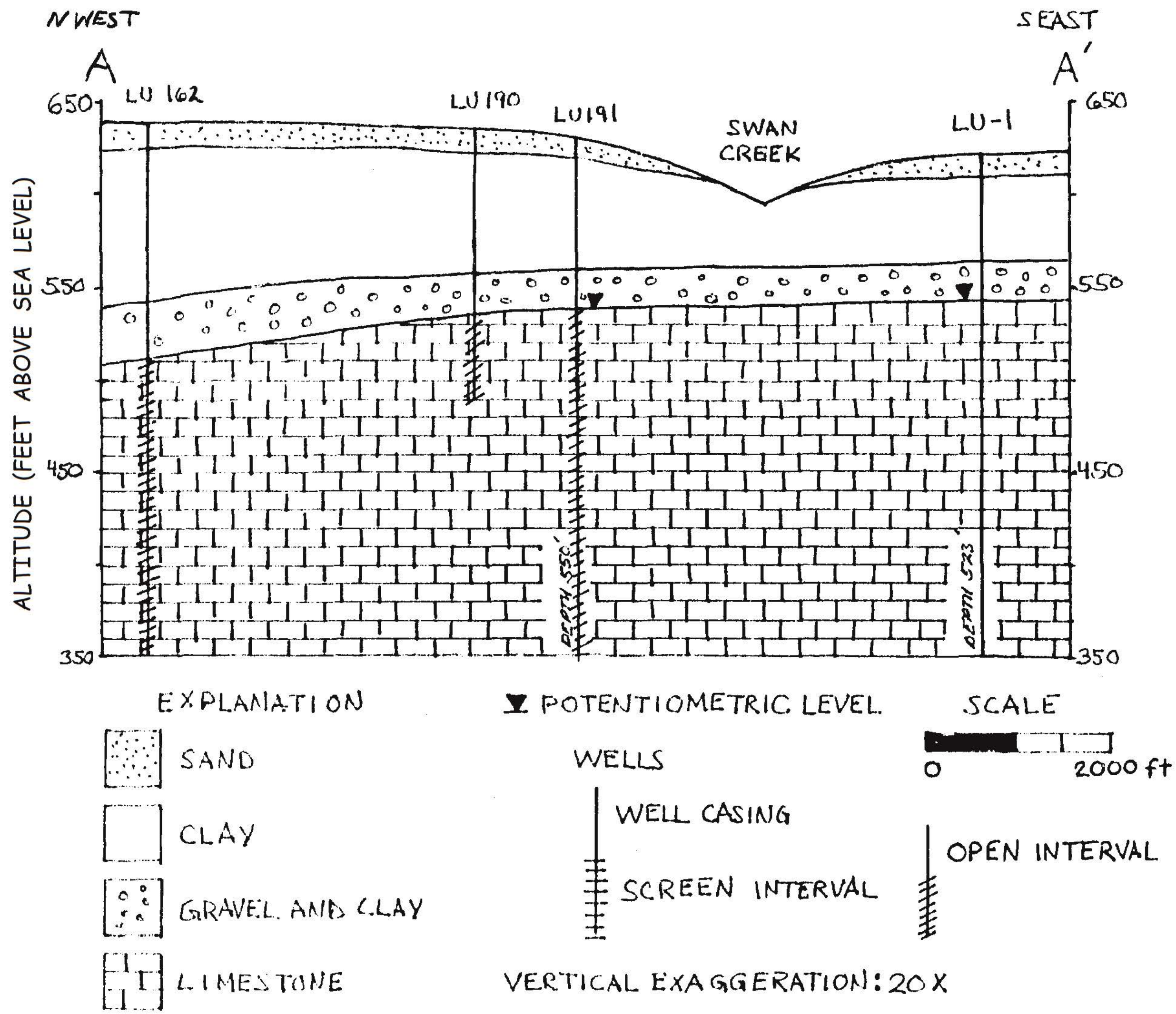


BU-56 BUTLER COUNTY

shows how recharge to these types of aquifers occurs directly from infiltration of precipitation and streamloss.Table 1 lists the observation wells completed into unconfined aquifers along with their location, construction characteristics and aquifer descriptions.

Of the nine observation wells studied that were completed in confined aquifers, six tapped unconsolidated deposits of sand and gravel of Pleistocene age. Two wells were completed into Silurian limestone, whereas one well was completed into Mississippian sandstone. Figure 6 is a hydrogeologic cross section through a confined aquifer and shows a thick, relatively impermeable clay layer that constitutes the confining layer. All of these aquifers are confined by thick layers of clay or shale.Table 2 lists the construction characteristics of these wells,the composition of the aquifer, and the confining layer. Hydrogeologic cross sections of the aquifers that the wells examined were completed in are given in appendix C. Well logs which were used to construct these hydrogeologic cross sections are given in appendix D.

Figure 6. Hydrogeologic cross section of a confined aquifer.



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HYDROGRAPH ANALYSIS

All data compiled for this study were obtained from hydrographs measuring yearly water-level changes.The hydrographs utilized for this study were generated by the ADAPS computer system at the USGS based on data from the Observation Well Network maintained by the Ohio Department of Natural Resources. The sample hydrograph depicted in Figure 2 reveals the characteristic fluctuations in water levels of a typical aquifer during a water year and is a good representation of the typical durations and magnitudes of the recharge and discharge cycles. Hydrographs of the confined and unconfined aquifers examined in this study for all the years evaluated are given in appendix A. Following are the descriptions of how recharge characteristics were measured for this study based on the well hydrographs. Figure 7 shows how these measurements were made.

The duration of the recharge period corresponds to the time in weeks that water levels take to go from the yearly maximum depth below land surface to the yearly minimum depth below the land surface. On Figure 7, the time from point A to point B on the X axis represents the recharge period.

The apparent amount of recharge is the maximum depth below the land surface minus the minimum depth below the land surface and corresponds to the value on the Y axis at point A minus the value on the Y axis at point B.

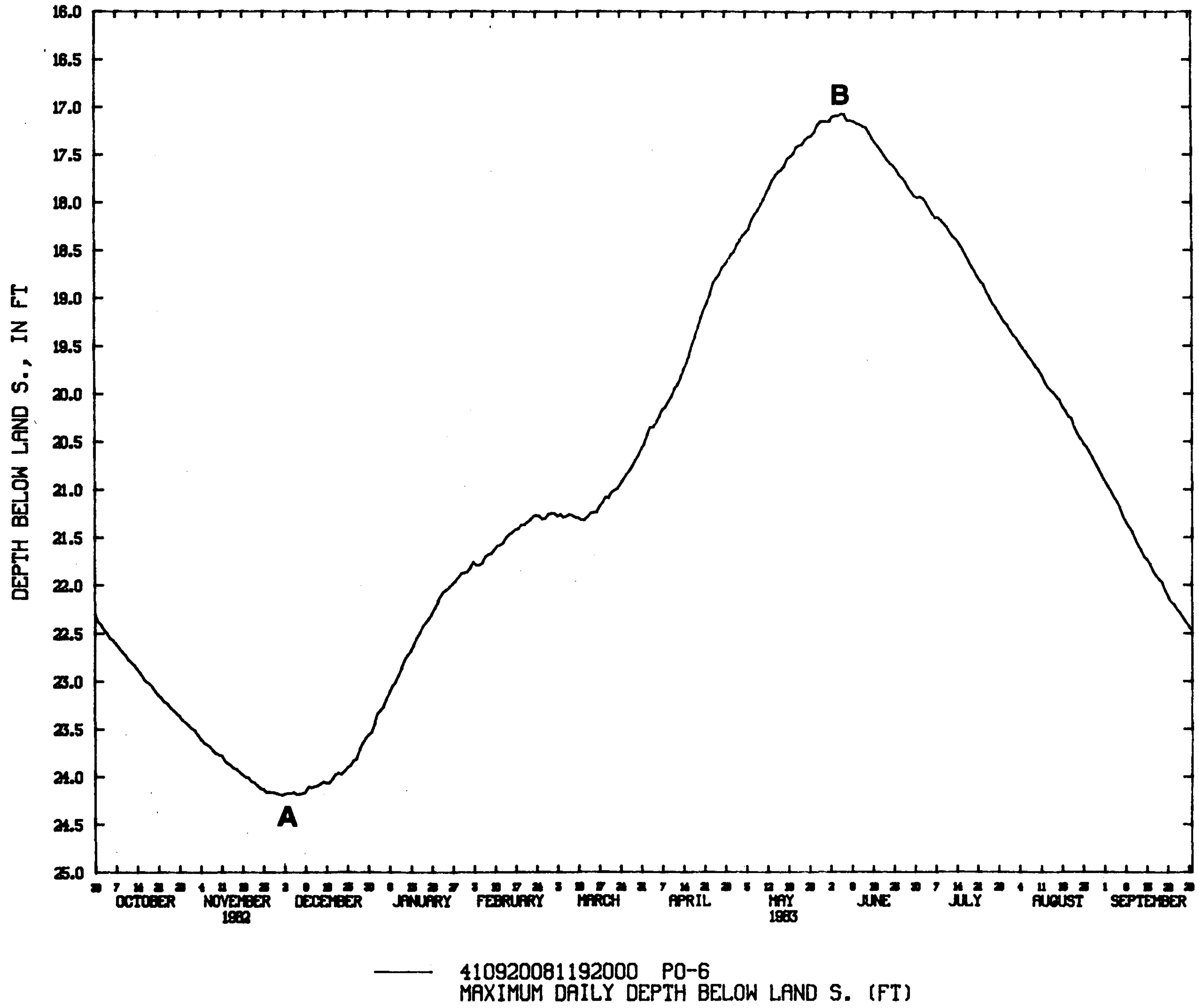
The duration of the discharge period is the time in weeks that water levels take to go from the yearly minimum depth below land surface to the maximum yearly depth below the land surface. On Figure 7, this corresponds to the time on the X axis starting at point B, and continues into the next water year.

The week of recharge commencement is the week of the year when water levels begin to rise in the aquifer from the yearly minimum depth below land surface. This corresponds to the week on the X axis at point A.

The week of cessation of recharge is the week at which water levels in the aquifer reach their greatest value; corresponding to the minimum yearly depth below the land surface. This is shown as point B in Figure 7.

Eight water years of data were collected for each of the 17 observation wells. As a result, these hydrograph characteristics were measured on a total of 72 hydrographs in confined aquifers and 64 hydrographs in unconfined aquifers. These data were then compiled in tables for each well. Table 3 is an example of 8 years of water-level data compiled from consecutive hydrographs. Appendix B lists these tables by well and gives values for each of the five catagories analyzed over the eight water years.

Figure 7. Hydrograph depicting measurement of recharge characteristics.



	WELL MT-3 (Unconfined Aquifer)				
Water Year	Duration of Recharge Period (Weeks)	Apparent Amount of Recharge (feet)	Duration of Discharge Period (Weeks)	Week of Recharge Initiation (calendar yr)	Week of Recharge Cessation (calendar yr)
1982-83	29	5.25	19	42	18
1983-84	29	12.75	22	40	17
1984-85	26	12	26	39	13
1985-86	25	11	27	39	13
1986-87	28	11	29	39	14
1987-88	20	14.5	23	45	12
1988-89	39	20.75	18	34	21
1989-90	33	12.75	16	39	20

Table 3.
Summary of Recharge Characteristics

STATISTICAL ANALYSIS

Compilation and evaluation of the data from each measurement category was done using the computer program GEOEAS. The results of the statistical evaluations are in the form of histograms and probability plots for each measurement category.

Unconfined Aquifers

The duration of the annual recharge period of Ohio's unconfined aquifers lasts an average of 23 weeks with a standard deviation of 9 weeks (see Figure 8).This equates to a recharge period that ranges from 3.2 to 7.5 months with a mean value of 5.3 months. Extremes for the annual recharge period for the wells studied are 4 weeks to 45 weeks. These data appear to be normally distributed as seen by the histogram and the straight line on the probabilty plot.

The apparent amount of annual recharge to unconfined aquifers averages 6.8 feet of water-level rise with a standard deviation of 4.3 feet (Figure 9).The probability plot for these data shows that 70% of the time recharge to the unconfined aquifers is less than 8 feet. The histogram of amount of recharge for unconfined aquifers produces a negatively skewed distribution, although when log normalized a more normal distribution is produced (Figure 10).

The duration of the annual discharge period has a mean of 27 weeks and a standard deviation of 8.4 weeks (Figure 11) This gives the discharge period a range of 4.3 to 8.3 months with 6.3 months representing the mean. These data produce a fairly normal distribution with the mean and median being 27.7 and 28 weeks, respectively. The range of data for this catagory include a minimum value of 13 weeks and a maximum value of 60 weeks.

Commencement of the annual recharge period normally begins in the 41st week of the calendar year, with a standard deviation of 10 weeks. This corresponds to recharge beginning, on average in the second week of October with a range from the first week of August to the last week in December. The probability plot of these data indicates that recharge begins by the 45th week of the calendar year 70% of the time (Figure 12 b).

On average the cessation of the annual recharge period occurs by the third week in May with a range of extremes from the second week of March to the middle of July (Figure 13). This agrees well with seasonal weather patterns as prevailing warmer weather in May increases evaporation levels and the majority of plants and crops are in full growth stage by this time. The aquifers examined in this study had ceased recharge by dates ranging from the 1st to the 30th week of the year.

Confined Aquifers

The duration of the annual recharge period to Ohio's confined aquifers averages 28 weeks or 6.5 months with a standard deviation of 9.5 weeks (see Figure 14). Data for this catagory are normally distributed. Probability plots indicate that 70% of the time the recharge period lasts less than 34 weeks (Figure 14 b). Extremes for these data ranged from 8 to 49 weeks.

The apparent amount of annual recharge in the confined aquifers produces a mean of 4.5 feet of water level rise with a standard deviation of 2.7 feet (see Figure 15). An inspection of the probability plot reveals that 70% of the time the amount of recharge is less than 6 feet. The histogram of annual amount of recharge is negatively skewed. However , once the log of each value is taken the data distibution is normalized (see Figure 16). This data set had values ranging from a minimum of 1ft to a maximum of 13 ft, which is a much smaller distribution than that for unconfined aquifers.

The duration of the discharge period for confined aquifers lasts 24 weeks with a standard deviation of 8.5 weeks (see Figure 17). This indicates an average discharge period of 5.6 months. The probability plot for these data indicate that the discharge period is less than 30 weeks long 70% of the time (see Figure 17 b). Seven weeks was the minimum value, whereas 44 weeks represented the maximum value.

Commencement of the annual recharge period averages the 42nd week of the year with a standard deviation of 7.6 weeks (see Figure 18). Thus, the recharge period for confined aquifers ranges from the end of August to the second week in November with the third week of October representing the average date of commencement. Extreme values for the commencement of recharge ranged from the end of May to the third week in Febuary.

Cessation of the annual recharge period has a mean value corresponding to the 18th week of the calendar year with a standard deviation of 8.6 weeks (see Figure 19). Data from the probability plot indicates that 90% of the time, recharge has stopped by the end of July. Times of cessation of recharge ranged from January to November.

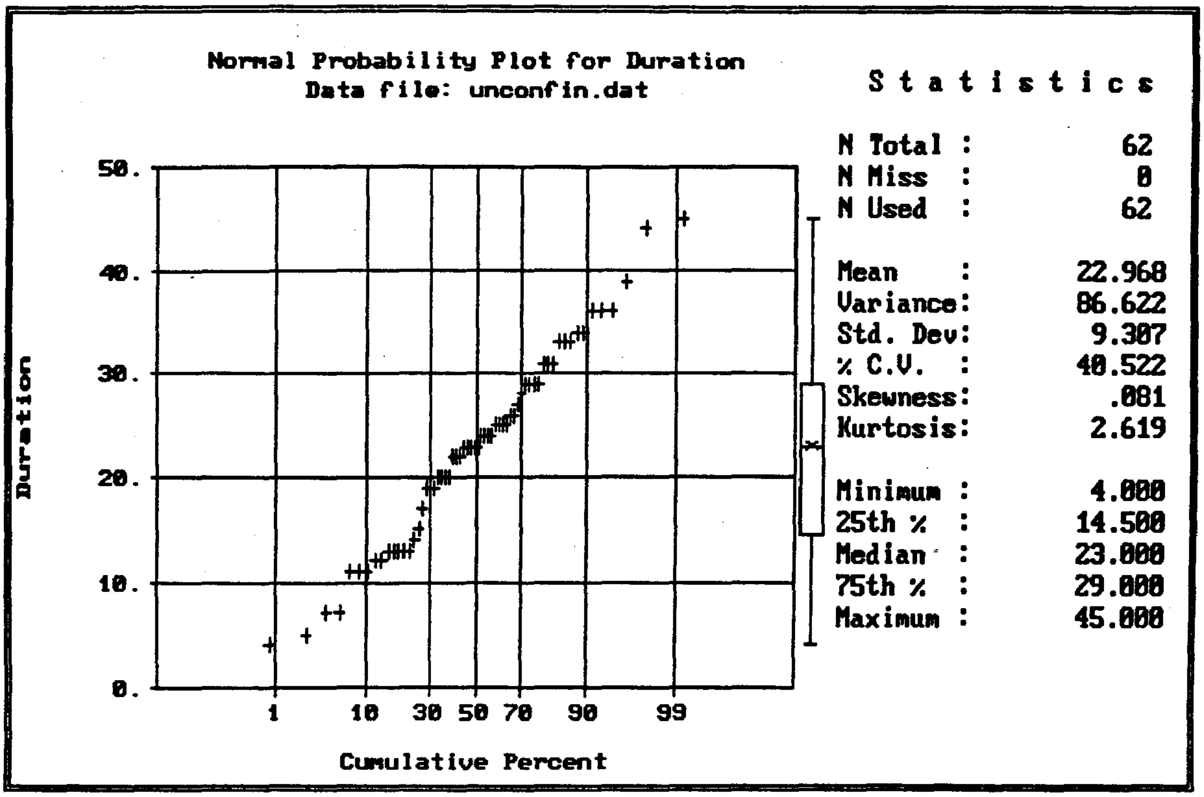
Comparisons

To make comparisons between the nature of recharge to confined aquifers and unconfined aquifers, the table below lists the mean values for each of the parameters analyzed in this study.

	Duration of recharge period (weeks)	Amount of recharge (feet)	Duration of discharge period (weeks)	Week of recharge commencement (calendar yr)	week of recharge cessation (calendar yr)
Unconfined:	22.9	6.8	27	41.2	19.5
Confined:	28.7	4.5	24.8	42.5	18.7

On an average basis, the duration of the recharge period in confined aquifers lasts 6 weeks longer than the duration of recharge to unconfined aquifers. The apparent amount of recharge to confined aquifers averages 2 feet less water-level rise than the apparent amount of recharge to the unconfined aquifers. The unconfined aquifers studied appear to have a slightly longer discharge period than the confined aquifers. This, possibly is due to their proximity to the land surface and their greater availability for transpiration and evaporation.

On average the commencement of the annual recharge period to Ohio's unconfined aquifers precedes that of the confined aquifers by one week. This agrees with the geology of these aquifers which dictates that water recharging the confined aquifers must pass through the unconfined aquifer and confining layer first, or must cause an increase in water level in the unconfined aquifer that is transmitted to the confined aquifer as an increase in confining pressure. Finally, the cessation of the recharge period for both confined and unconfined aquifers occurs during the 19th week of the year, which, on an average, equates to the second week in May.



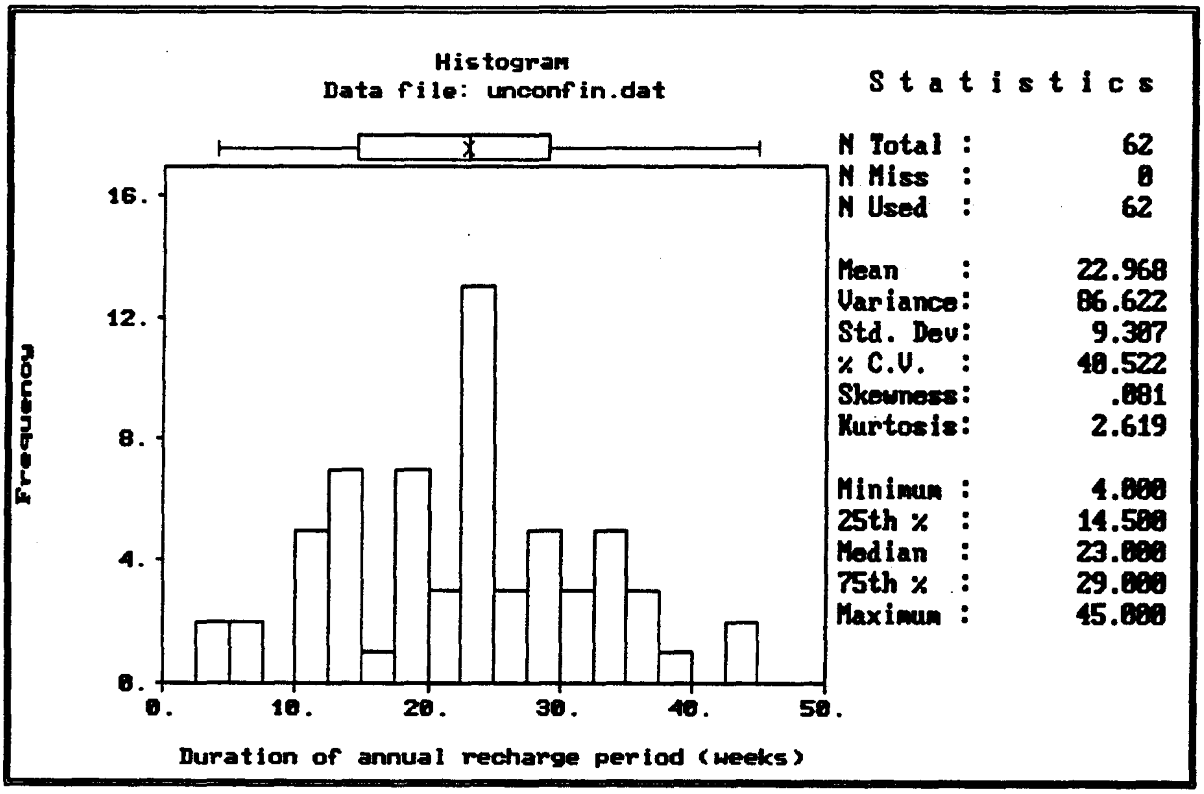
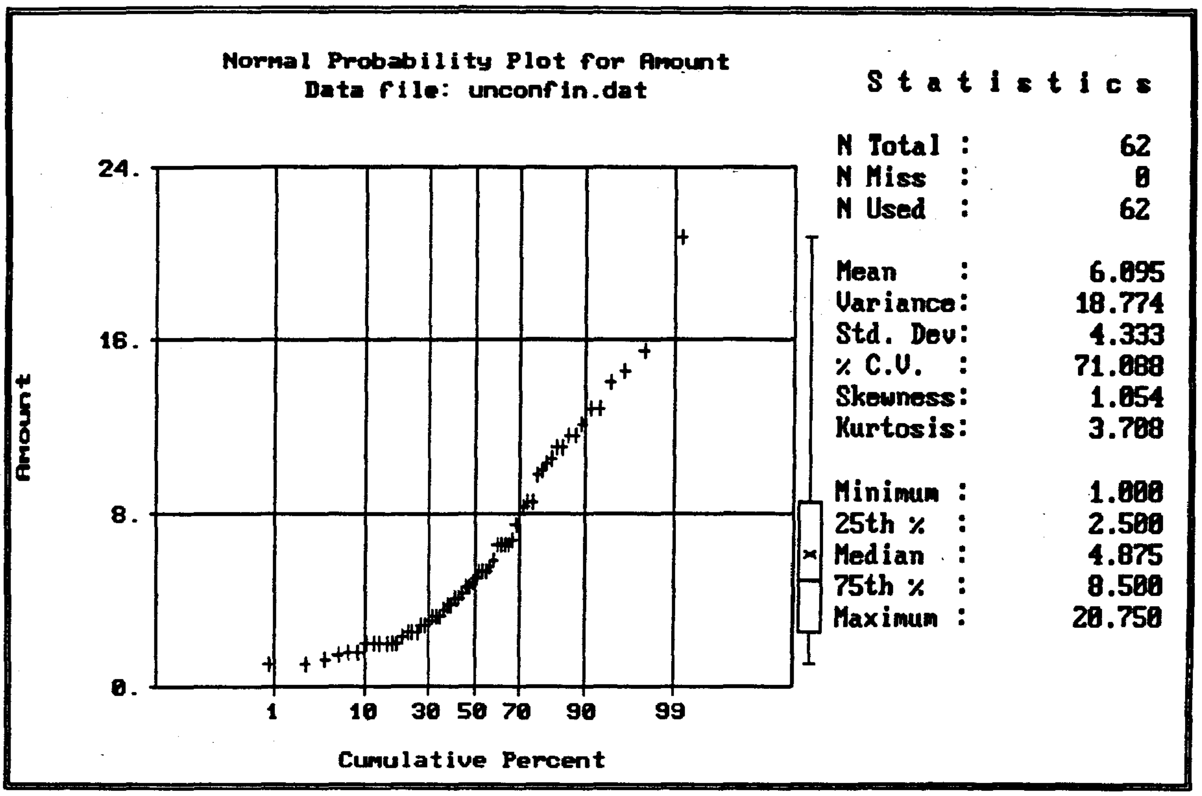


Figure 8a. Histogram of the duration of the annual recharge period.
8b. Probability plot of the duration of the annual recharge period.



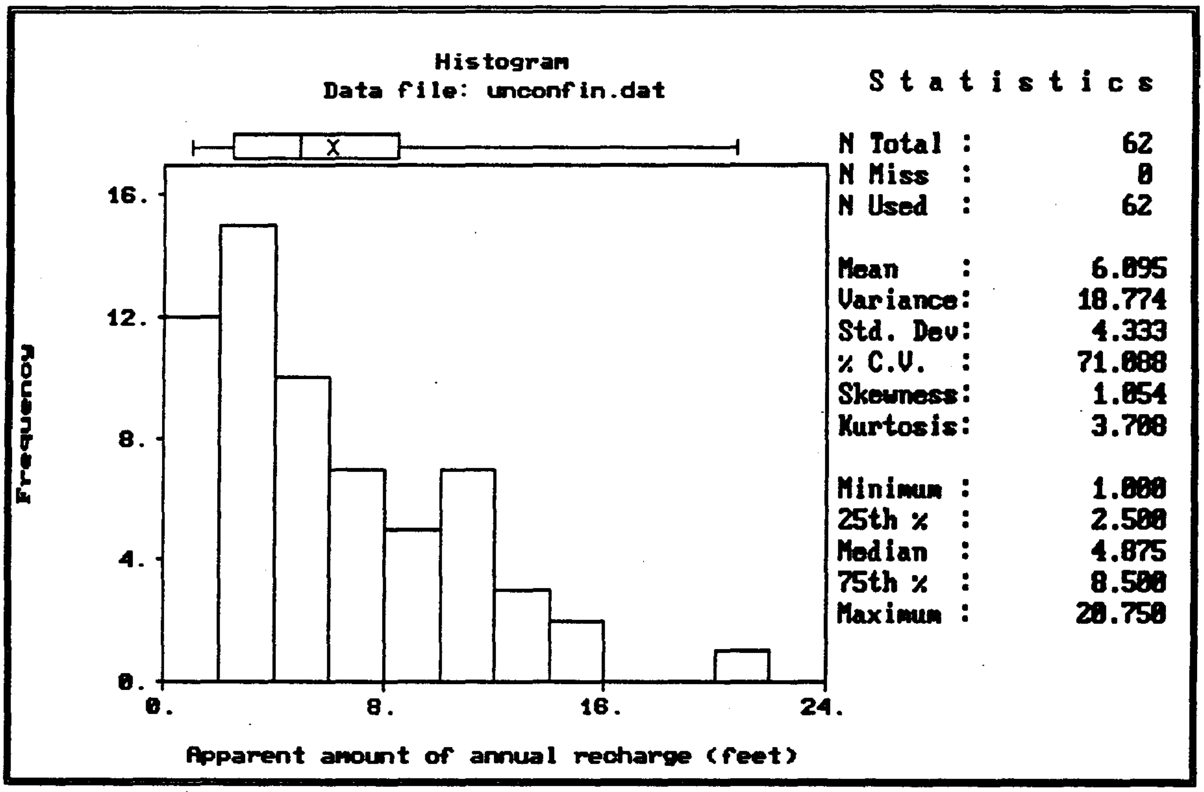


Figure 9a. Histogram of the apparent amount of annual recharge.
9b. Probability plot of the apparent amount of annual recharge.

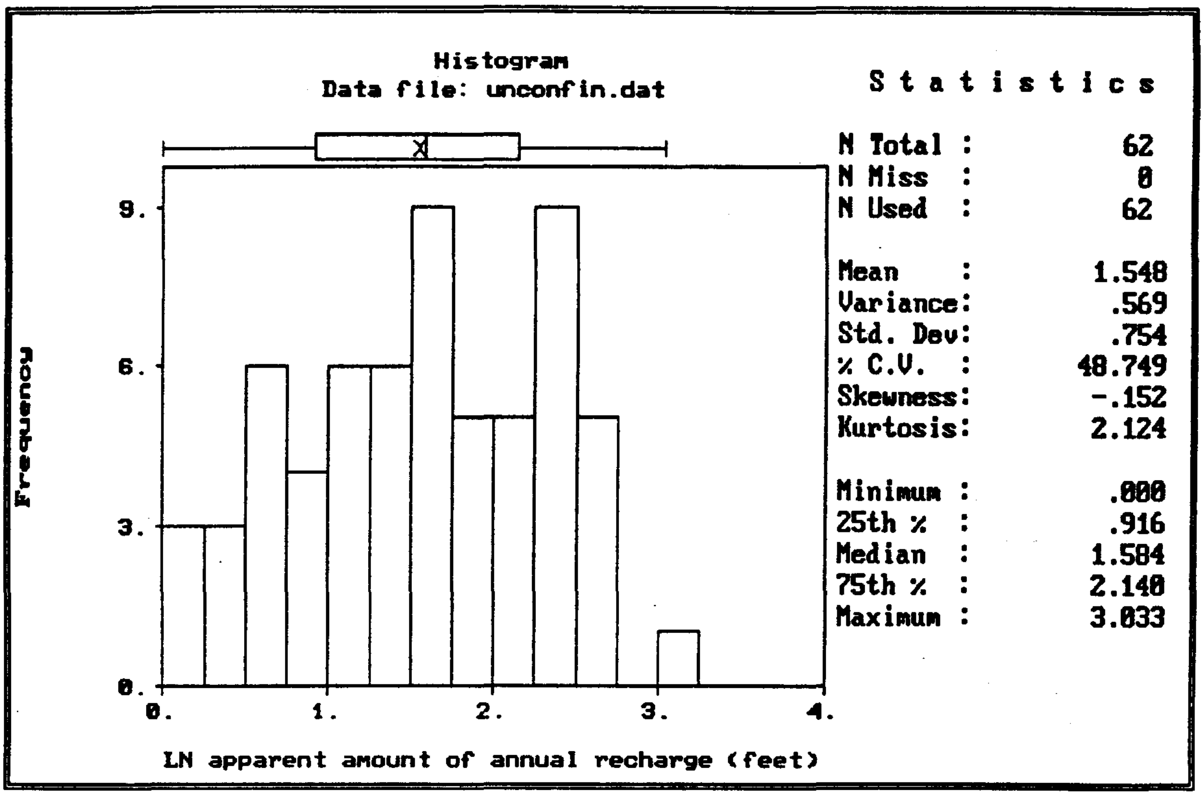
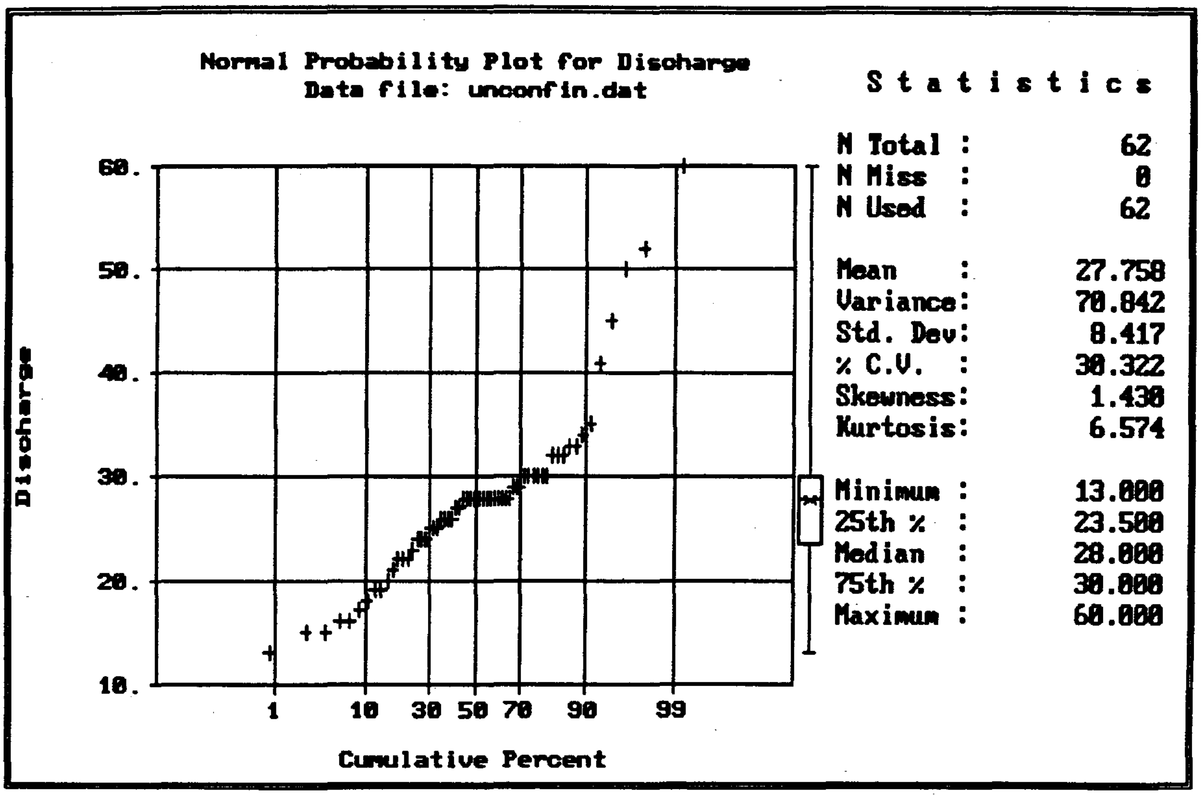


Figure 10. Log normalized histogram for the apparent amount of annual recharge.



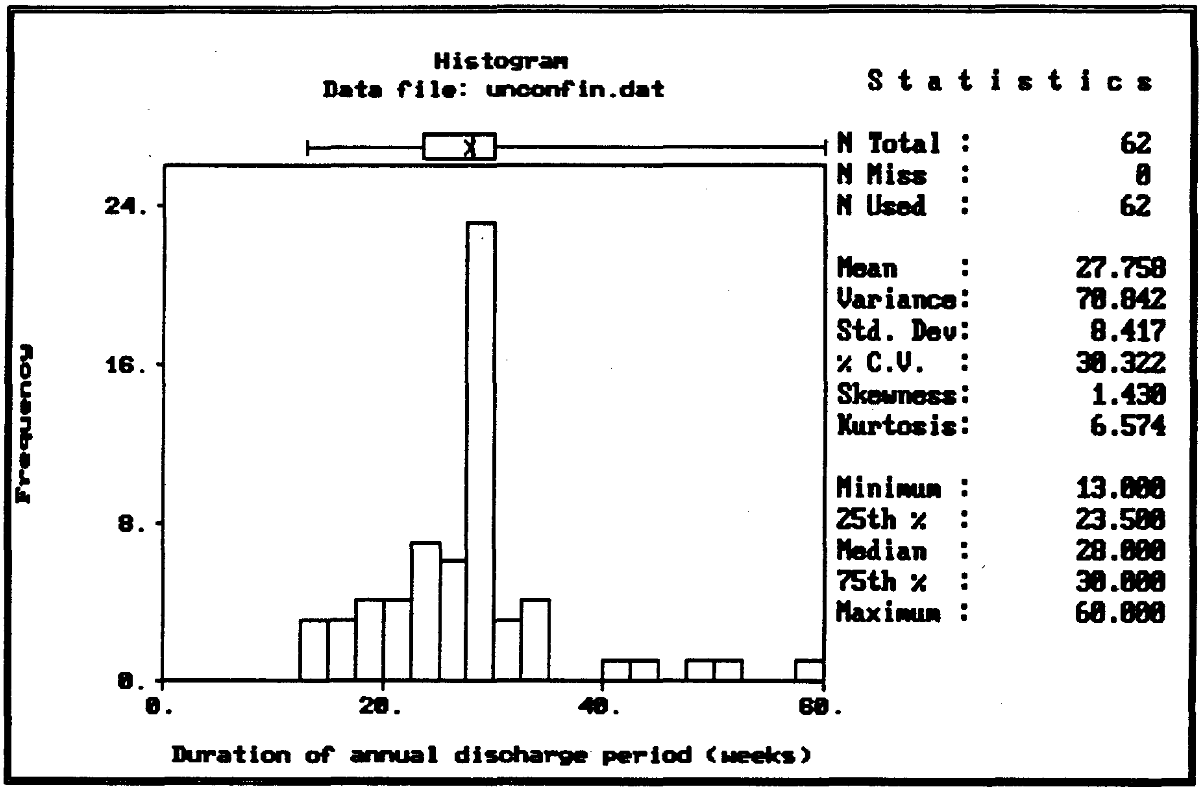
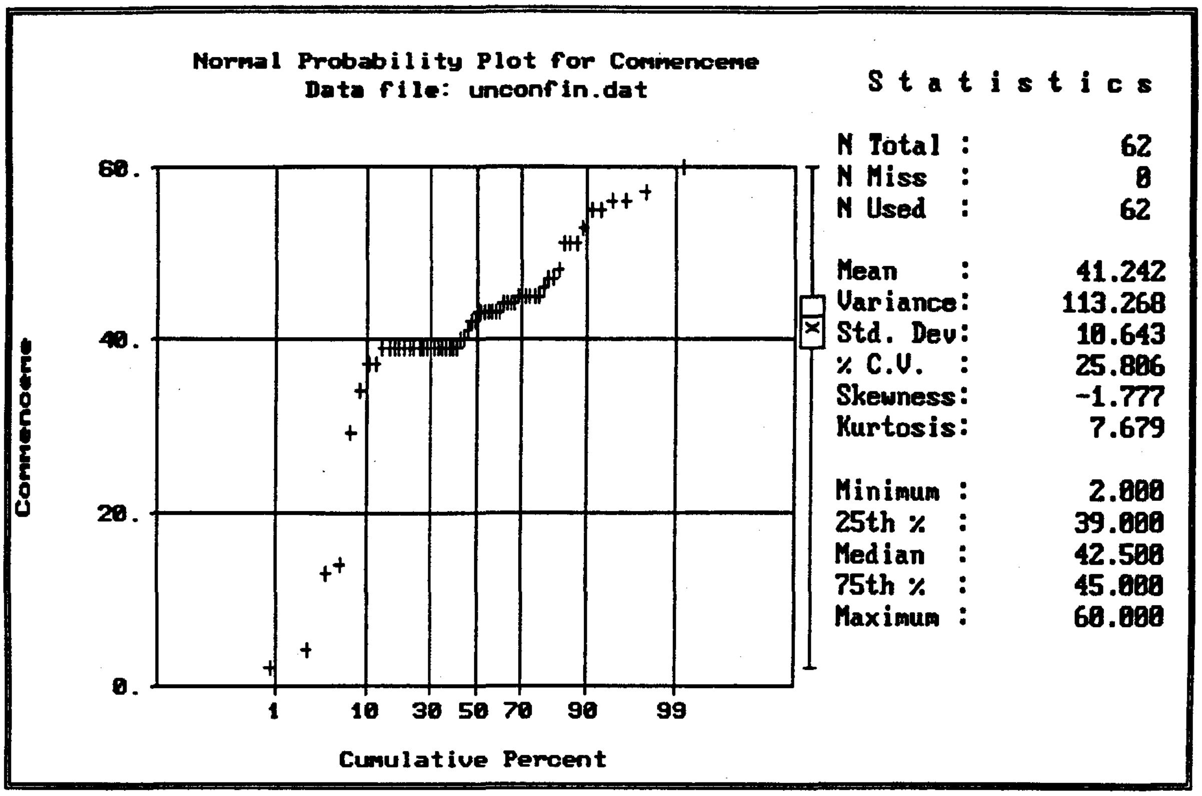


Figure 11a. Histogram of the duration of the annual discharge period.
11b. Probability plot of the duration of the annual discharge period



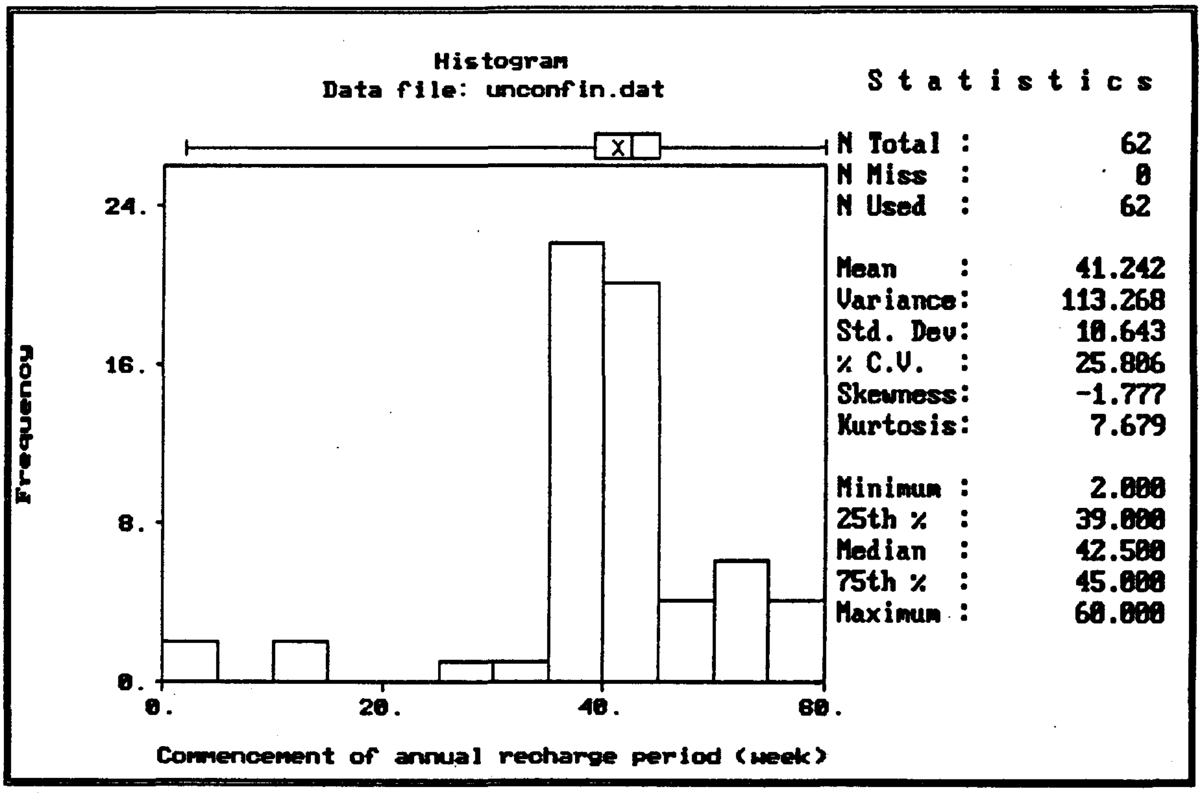
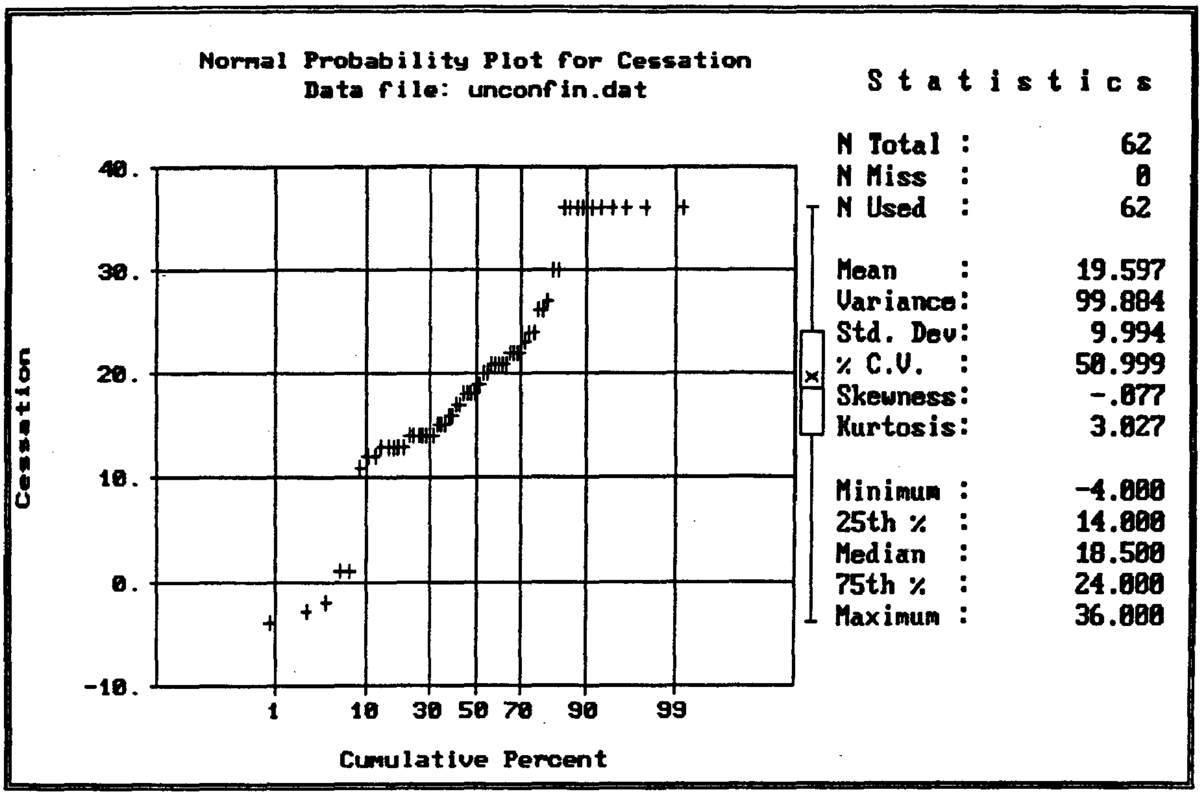


Figure 12a. Histogram of the commencement of the annual recharge period.
12b. Probability plot of the commencement of the annual recharge period.



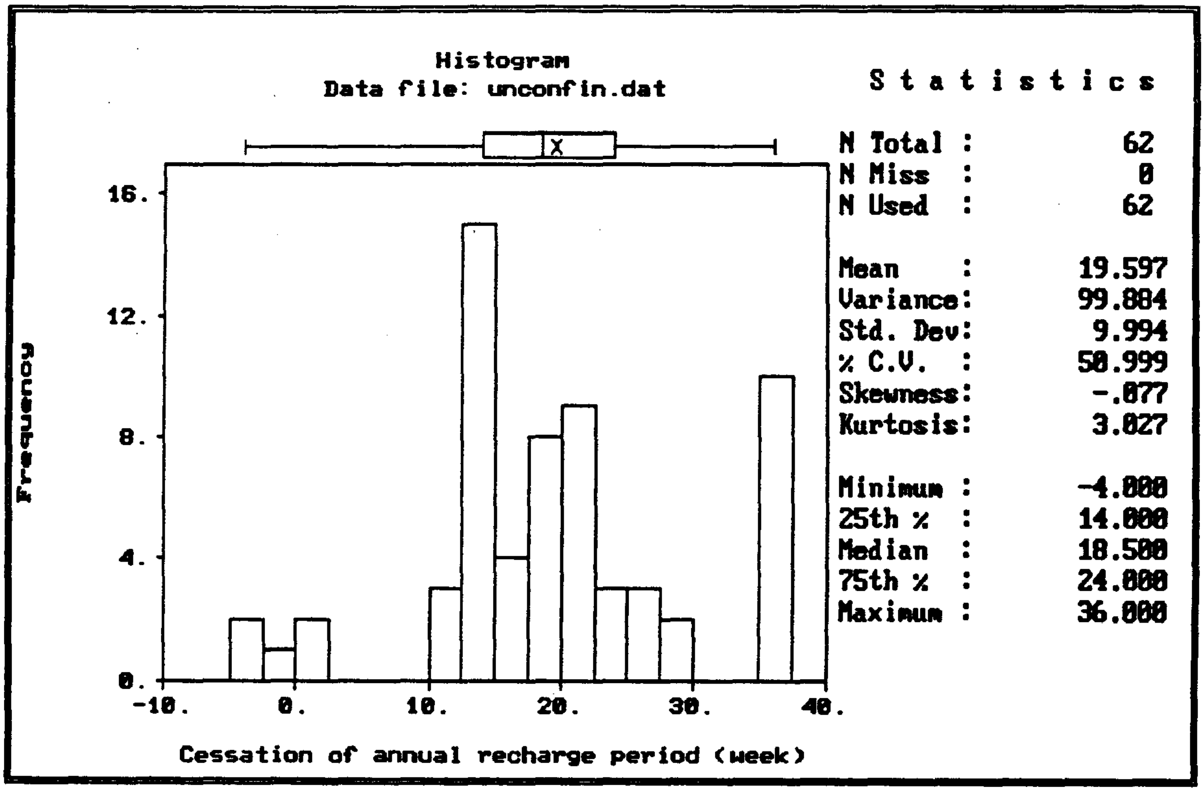
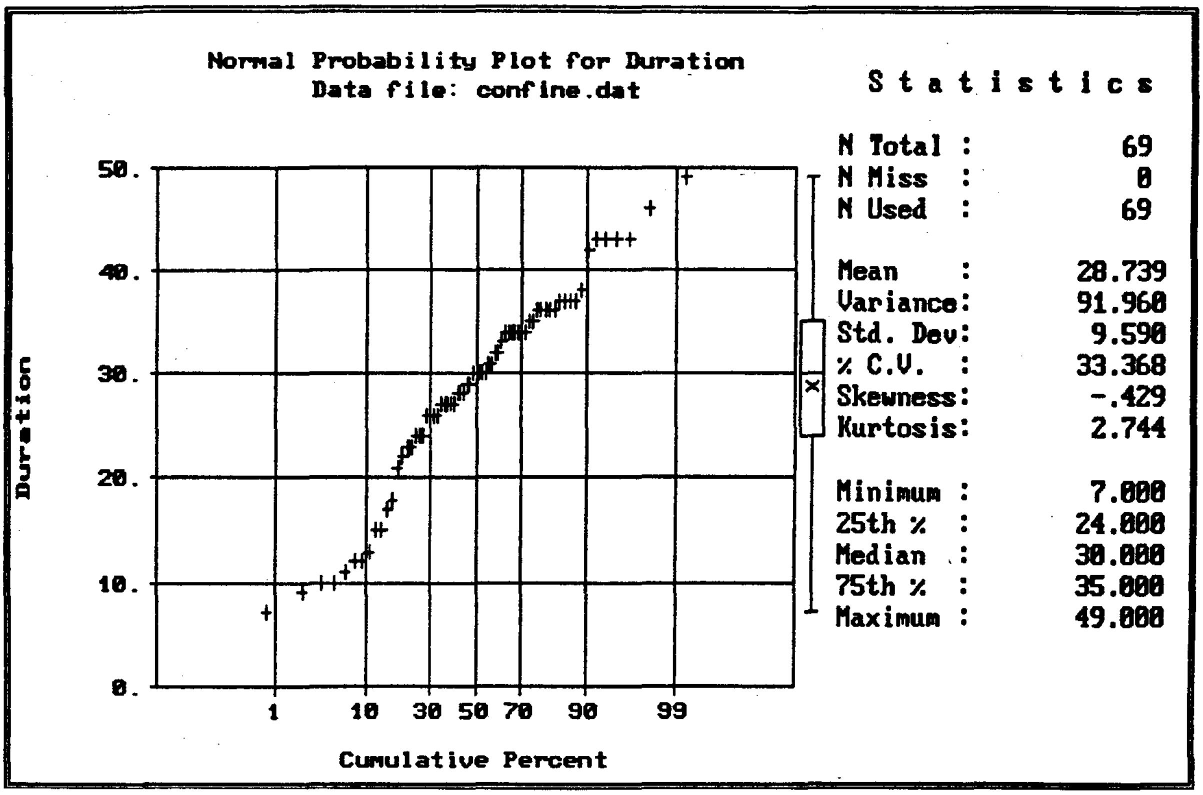


Figure 13a. Histogram of the cessation of the annual recharge period.
13b. Probability plot of the cessation of the annual recharge period.



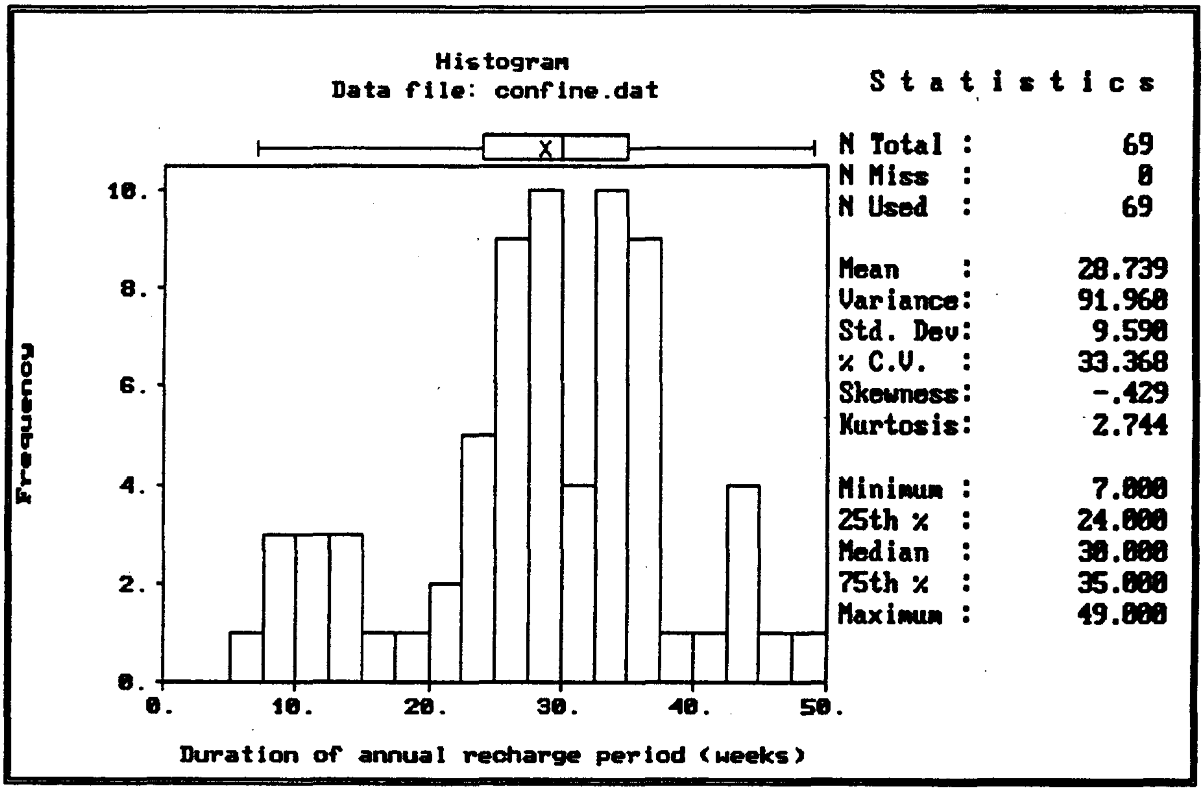
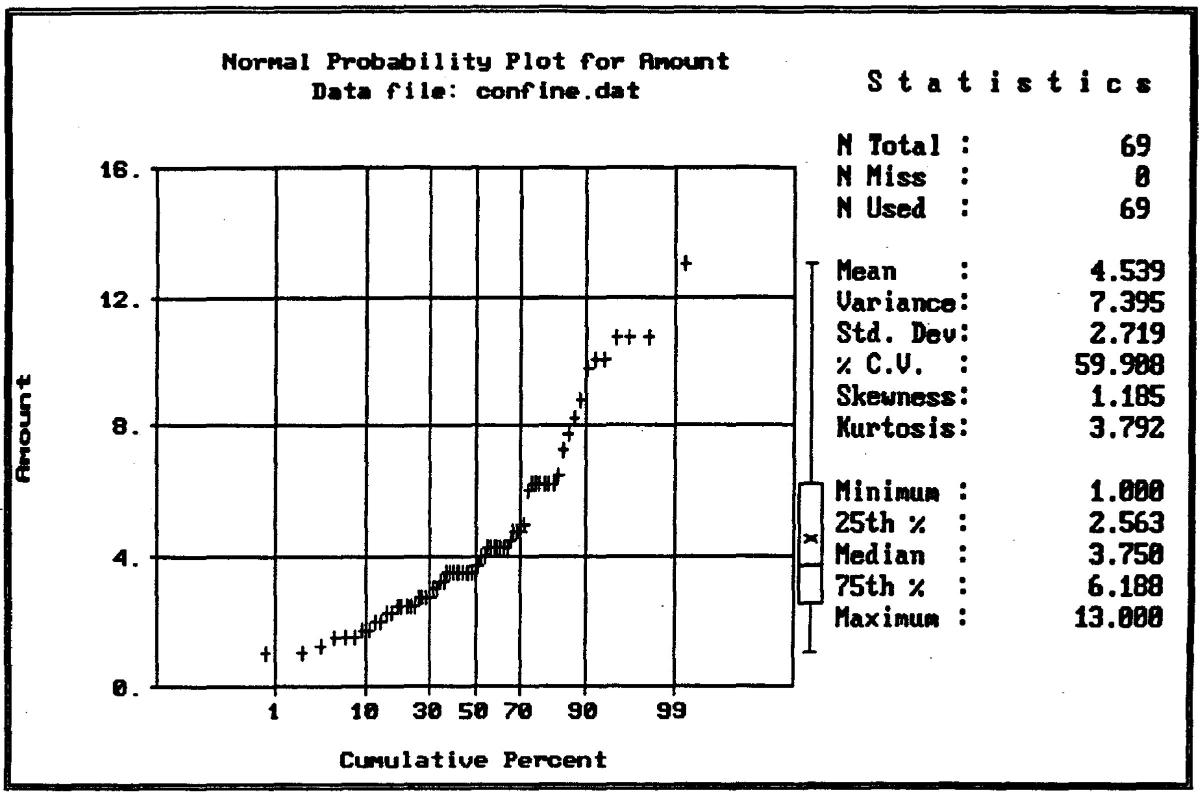


Figure 14a. Histogram of the duration of the annual recharge period.
14b. Probability plot of the duration of the annual recharge period.



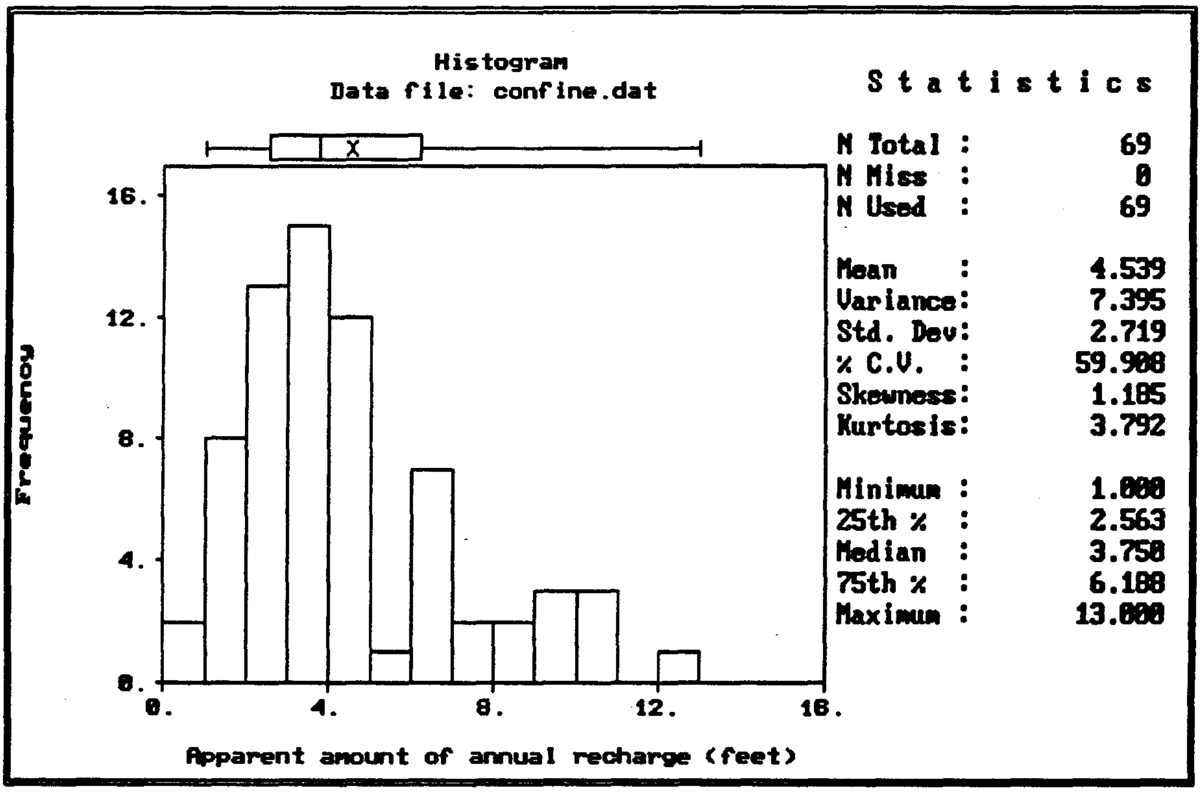


Figure 15a. Histogram of the apparent amount of annual recharge.
15b. Probability plot of the apparent amount of annual recharge.

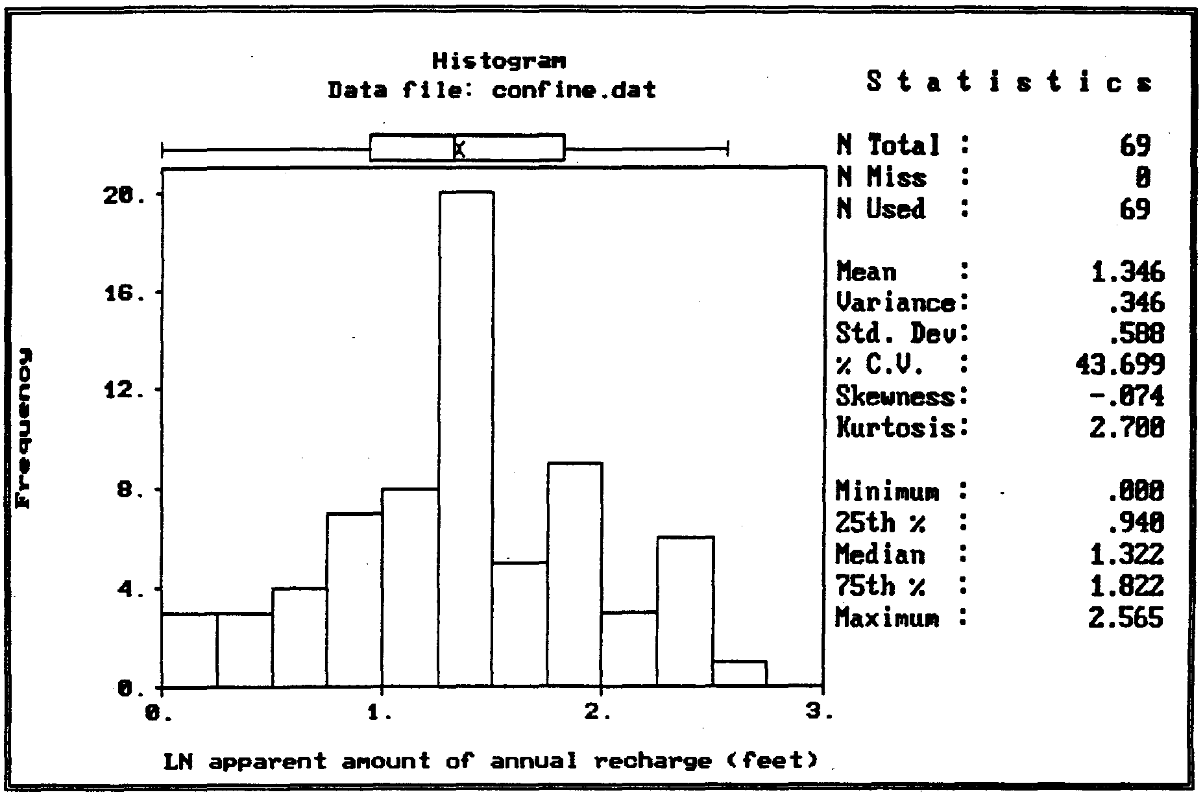
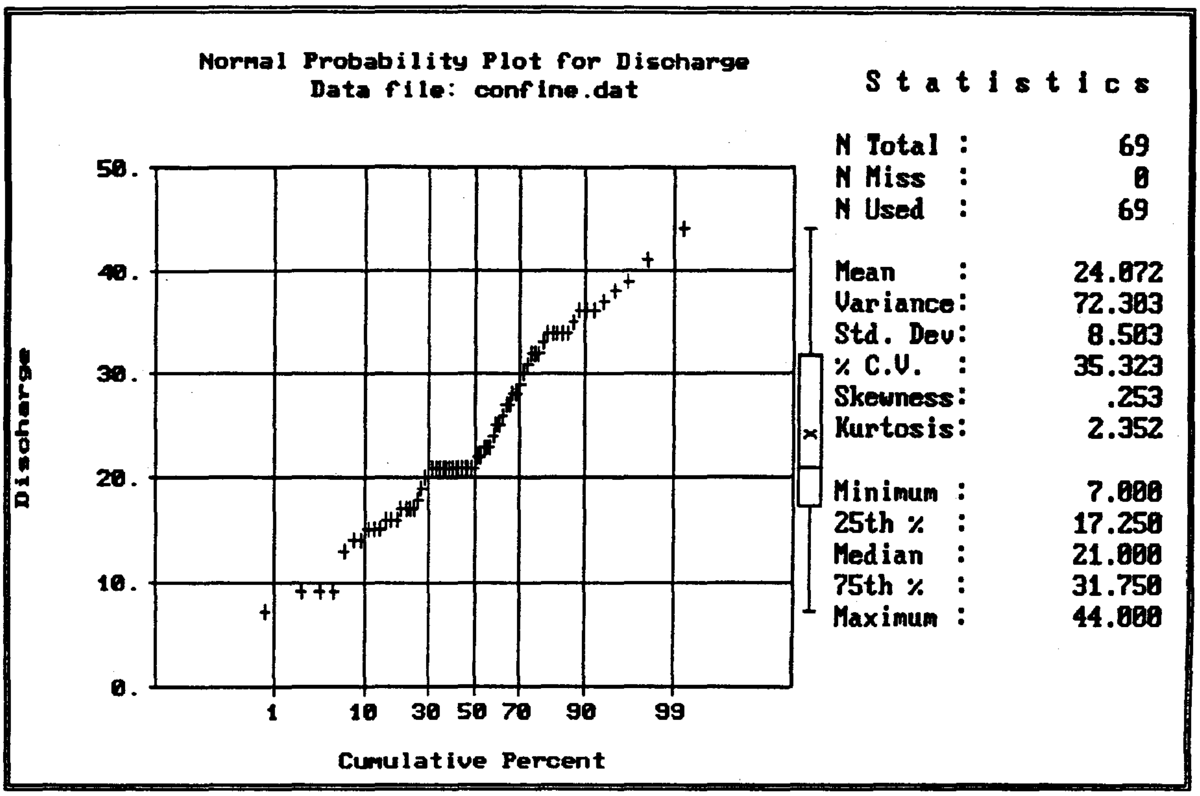


Figure 16. Log normalized histogram of the apparent amount of annual recharge.



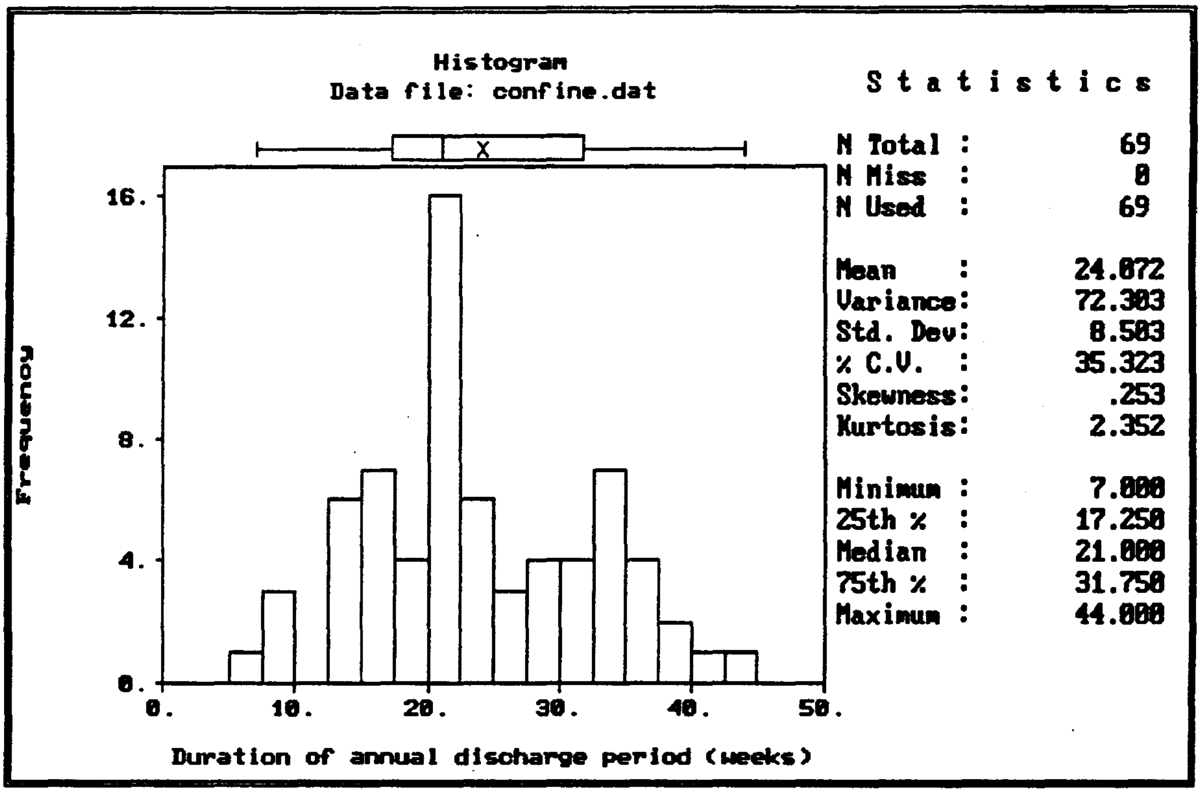
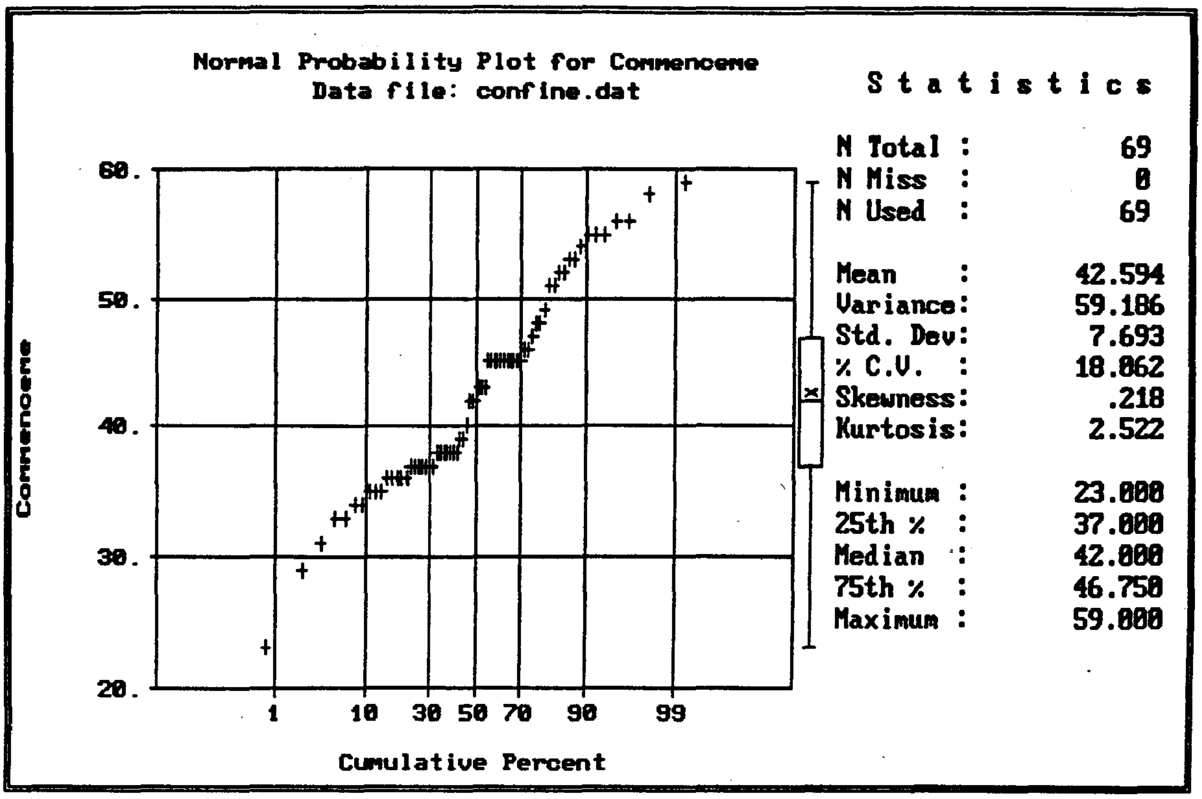


Figure 17a. Histogram of the duration of the annual discharge period.
17b. Probability plot of the duration of the annual discharge period.



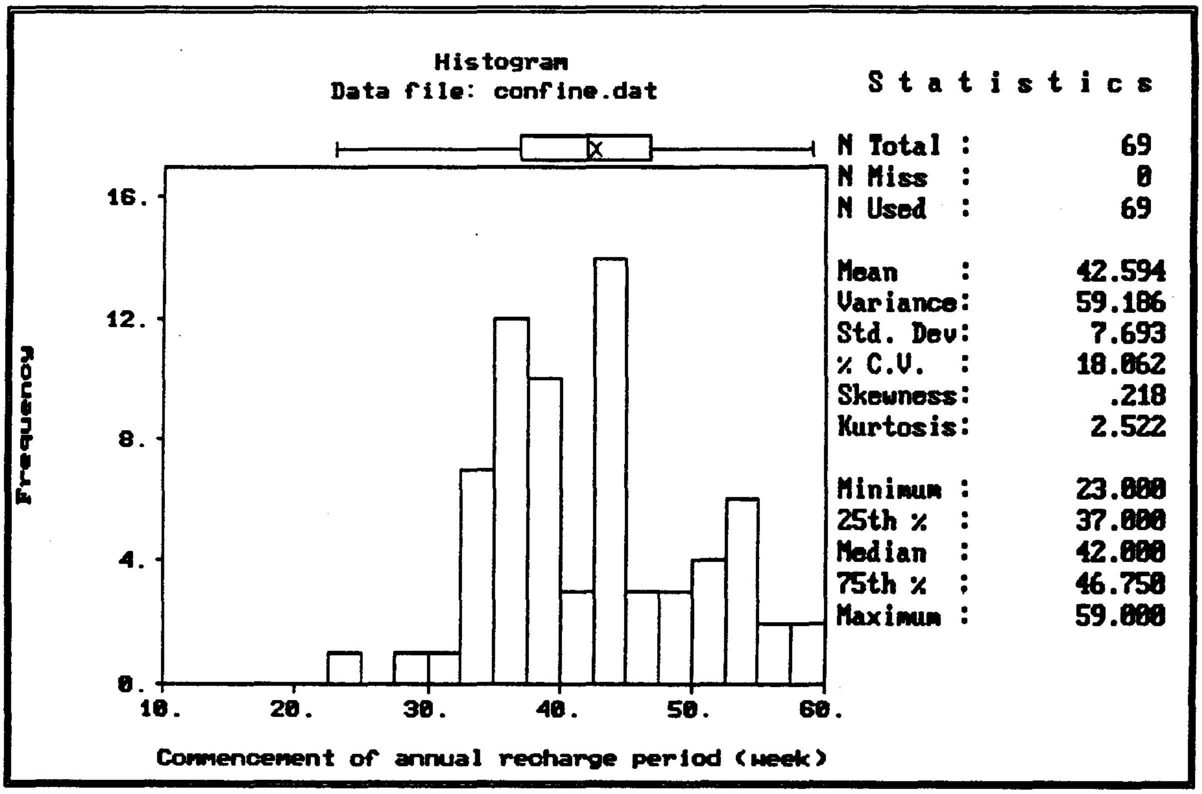
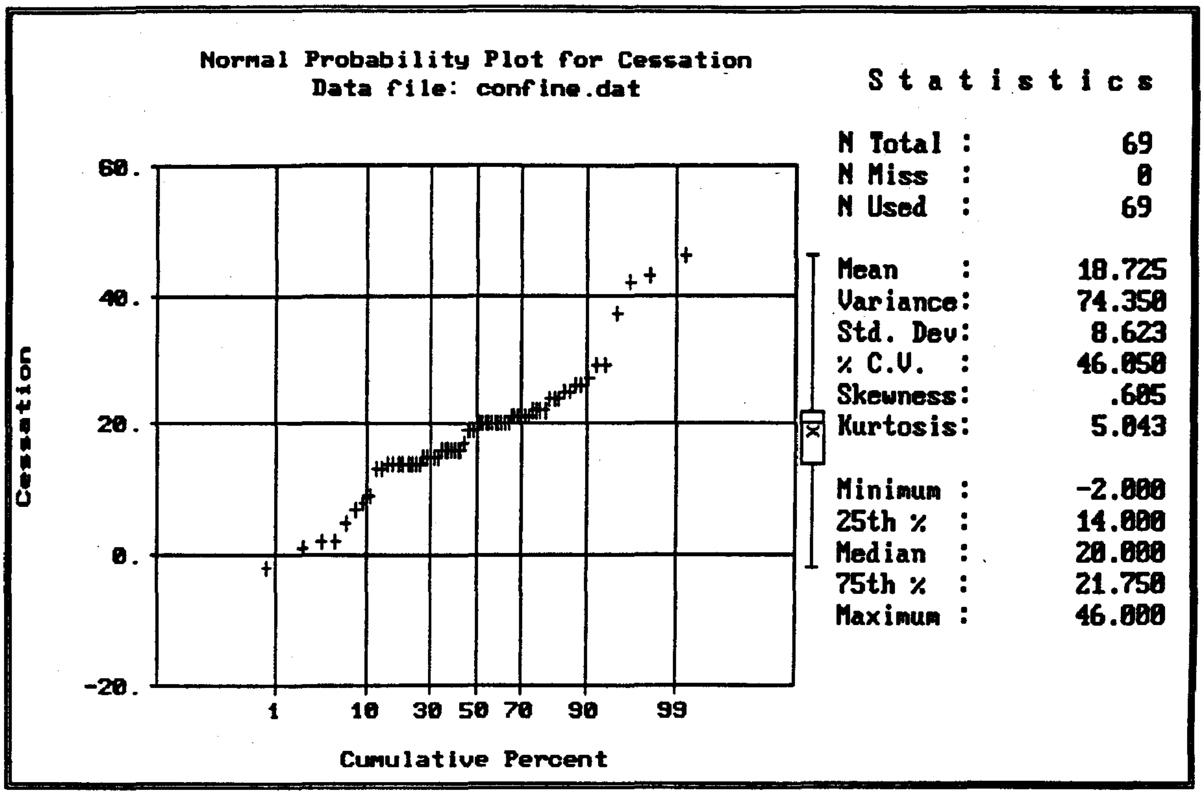


Figure 18a. Histogram of the commencement of the annual recharge period.
18b. Probability plot of the commencement of the annual recharge period.



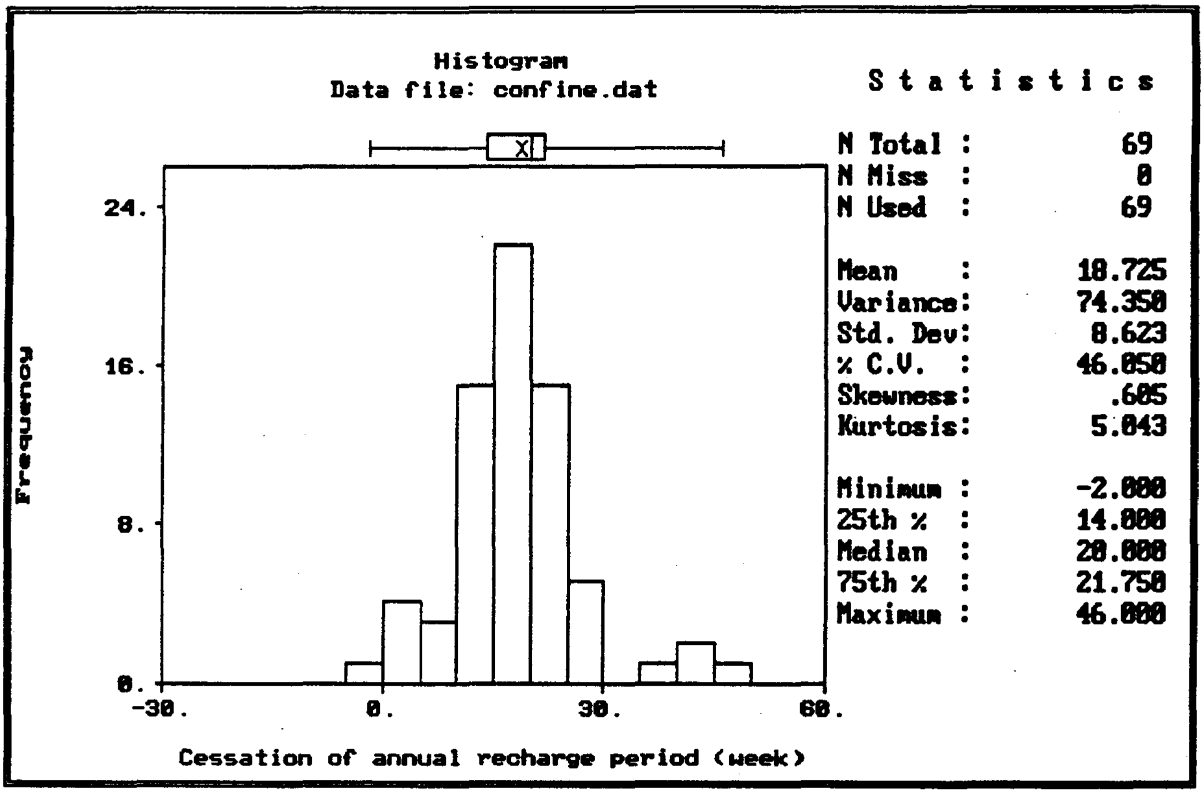


Figure 19a. Histogram of the cessation of the annual recharge period.
19b. Probability plot of the cessation of the annual recharge period.

SUMMARY AND CONCLUSIONS

The recharge characteristics of Ohio's confined and unconfined aquifers as evaluated by this study appear to agree well with their expected behavior although the range in values can be revealling. In a typical year, recharge to Ohio's aquifers begins during the month of October, generally lasting 6 months, and ends sometime during the month of May. The apparent mean amount of recharge ranged from 4.5 feet for confined aquifers to 7 feet of apparent water-level rise for unconfined aquifers. The duration of the discharge period for both types of aquifers lasted, on average, 6 months.

Although the 17 observation wells examined in this study only represent a small portion of the 431 wells in the Ohio observation well network, it is likely that the results of this statistical analysis represent a fairly accurate approximation of the characteristics of recharge to Ohio's aquifers. It is important to note that these values do represent an average or mean value and that all of these catagories displayed signifigant extremes and ranges.

Seasonal water-level fluctuations of aquifers are important characteristics to follow and attempt to predict. Knowledge of the average range of of water-levels in an aquifer can be of great help in the construction of wells. Although low water levels can cause wells to become dry, rising water levels can cause aquifers to become contaminated when the water table reaches contaminants stored in the saturated zone. Additionally, fluctuations of the water levels can cause changes in water-level gradients which in turn can lead to directional changes in ground-water flow. Monitoring water levels over long periods can uncover long-term trends such as lowering of the water levels due to drought or overpumping of the aquifer. Establishing a methodology for statistically evaluating the characteristics of recharge to ground-water levels presents an invaluable tool for better management of water resources.

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